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WATER QUALITY CONTROL IN MINE SPOILS UPPER COLORADO RIVER BASIN

David B. McWhorter, et al

Colorado State University

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The purpose of this study was to identify potential water quality problems associated with runoff and percolation through mine spoils at selected sites in the Upper Colorado River Basin. The results show that the production of soluble salts from mine spoils into receiving waters is probably the most significant water quality problem that can be expected. No significant release of heavy metals was observed in the coal mine spoils studied. Some significant heavy metal concentrations were observed in the stream below the tailings disposal area from a copper-lead-zinc mill. A portion of these metals are contributed by the tailings, but a variety of old mines and mine dumps also make a contribution. The quality of percolate and runoff from spoils was found to correspond to the constituents of extracts prepared from saturated pastes of the spoil material. A method of estimating salt production into receiving waters was derived and found to agree very well with measured salt pickup at one coal site. The minimum quantities of salts that will eventually be released from the spoils studied are estimated.

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WATER QUALITY CONTROL IN MINE SPOILS

UPPER COLORADO RIVER BASIN

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

studies on the effects of environmental contaminants on man and the biosphere, and

a search for ways to prevent contamination and to recycle valuable resources.

To meet the energy demands of this Nation, the coals of the western United States must be exploited. This study is one of the first to assess the potential degradation of ground and surface waters by surface mining. Surface coal mines in Colorado and New Mexico were studied for a year, and in addition, the potential water quality problems from a copper-zinc-lead mill were evaluated.

A. W. Breidenbach, Ph.D.
Director
National Environmental
Research Center, Cincinnati

ABSTRACT

Mining is an extractive industry, and the potential for adversely effecting land and water utilization by other industries or municipalities may be large. The purpose of this study was to identify potential water quality problems associated with runoff and percolation through mine spoils at selected sites in the Upper Colorado River Basin, and to provide a quantitative description of the interactions among geological, chemical, hydrological, and meteorological variables influencing potential water quality degradation.

The results of this study show that the production of soluble salts from mine spoils into receiving waters is probably the most significant water quality problem that can be expected. No significant release of heavy metals was observed in the coal mine spoils studied. Some signifcant heavy metal concentrations were observed in the stream below the tailings disposal area from a copper-zinc-lead mill. A portion of these are contributed by the tailings, but a variety of old mines and mine dumps also make a contribution. The quality of percolate and runoff from spoils was found to correspond to the constituents of extracts prepared from saturated pastes of the spoil material. A method of estimating salt production into receiving waters was derived and found to agree very well with measured salt pickups at one coal site studied. The minimum quantities of salts that will eventually be released from the spoils studied are estimated.

This report was submitted in fulfillment of Grant No. R802621 by Colorado State University under the sponsorship of the Environmental Protection Agency. Work was completed as of June 30, 1974.

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Mr. J. A. Brookman and Mr. P. Hammer, research technicians, spent many hours of their own time attending to the details of sample collection, chemical analysis, and field data collection. The conditions were often adverse, making it necessary to use snowshoes and skis at temperatures which fell below -30°F. The efforts of these individuals and those of Mrs. D. English in doing all the typing for the project are greatly appreciated.

Finally, the advice of Mr. E. C. Grim, EPA project officer, and Mr. R. D. Hill, Chief of Mine Drainage Pollution Control Activities, is appreciated. Their experience with similar investigations at other locations and their contacts with other investigators were very helpful.

SECTION I
CONCLUSIONS

The most significant water pollution potential of the coal strip mine spoils investigated results from the soluble salt content of the overburden materials. The major constituents in surface and subsurface runoff from the spoils are sodium, calcium, magnesium, sulfate, and bicarbonate. The principal sources of sulfate are probably epsomite and gypsum. Sodium in the runoff, apparently, results from being flushed from cation exchange sites on the clay particles in the spoil. These conclusions are expected to apply, in different degrees, to the majority of strip mine spoils in the Rocky Mountain and Northern Great Plains regions. This is true because almost all the surface mineable coal reserves reside in formations of Upper Cretaceous and Early Tertiary age, formed under generally similar geologic conditions.

The minimum soluble salt contents of the two coal mine spoils studied are 2.4 and 23 kilograms per cubic meter of spoil. These results do not include the effects of weathering and microbial activity that will tend to increase the quantity of salts available for removal by water. The 2.4 kilograms of soluble salt per cubic meter derived for the Edna Mine on Trout Creek was determined using 34 samples from 12 locations covering the entire disturbed area, and is believed to be reasonably representative of the exposed spoil. The chemical characteristics of samples of the Edna spoils and overburden exhibited a great deal of uniformity. The 23 kilograms per cubic meter determined for the Navajo Mine was derived from 3 samples formed by compositing 11 samples by depth interval. All of these samples were collected in a relatively localized area in one pit. Thus, the reported soluble salt content is not representative of the entire disturbed area at the Navajo Mine. Utah International personnel report a great deal of variability in spoil and overburden characteristics.

A net salt pickup of 6187 metric tons (6700 tons) over a nine month period was observed between monitoring stations upstream and downstream of the Edna Mine on Trout Creek. Salt pickup measured on one portion of the spoil area was found to be 8.42 metric tons per hectare (3.7 tons/acre) in a surface and subsurface runoff of 40 cm (16 in). The measured normalized rate of salt pickup is 0.21 metric tons per hectare per centimeter of surface and groundwater runoff (0.23 tons/acre/in). Over 80 percent of the total load was contributed during the spring runoff in April, May and early June. For perspective, the annual salt pickup from irrigated crop land in Grand Valley, Colorado is about 27 metric tons per hectare (12 tons/acre). Runoff at the Edna site was abnormally high during the period of this study and the above quantities are not representative of the average condition. Additional water quality and quantity measuring stations are being established at the Edna site, and the above figures will be continually refined through June, 1976.

Estimated average annual salt pickup rates for the Edna and Navajo spoils are 5.5 metric tons per hectare per year (2.4 tons/acre/yr) and 1.4 metric tons per hectare per year (0.6 tons/acre/yr), respectively. The net additional salt pickup caused by mining at the Navajo site is significantly lower than the above figures because the natural surface and subsurface runoff contains a relatively high concentration of dissolved solids. The potential net additional salt pickup caused by mining at the Edna Mine is not known precisely because the salt production from the watershed above the mine is derived from geologic materials that are not the same as those forming the spoil banks. Salt production from the Edna spoils per unit area is more than 10 times greater than the salt production from the upstream watershed, however.

Because of the difficulties involved in making accurate estimates of the average annual surface and subsurface runoff, the average annual salt pickup rates reported above should be regarded only as indications of the magnitudes of average salt loading. The normalized salt pickup rate (mass of salt per unit area per unit of surface and subsurface runoff)

used for the Navajo Mine was calculated from the results of saturated paste extracts and was not verified by direct measurement due to limitations of time and budget. The salt pickup rate for the Navajo Mine is expected to vary over a range corresponding to the range of spoil variability. The configuration of the graded spoils at the Navajo Mine precludes significant quantities of surface runoff beyond the boundaries of the disturbed area, and the estimated salt pickup refers to deep percolation (subsurface runoff). Given that our estimates of subsurface runoff are reasonable and that the existing groundwater was highly mineralized prior to mining. the pollution potential of the Navajo spoils must be regarded as very low. Reclamation procedures involving spoil manipulation and revegetation, currently being researched and practiced by Utah International, should result in a return to the atmosphere of essentially all incident precipitation.

A reliable, and probably conservative, index of the potential salt production from the spoils studied is obtained by chemical analyses of saturated paste extracts. The concentration of salts present in the extracts from Edna samples, when combined with runoff volumes, resulted in a calculated salt pickup rate that agreed very closely with the measured value. Order of magnitude estimates of salt loading from a proposed mining site can be made from extract analysis of overburden core samples and hydrologic information prior to mining activity. Optimum placement of spoils for salt pickup control can also be judged from a saturated paste extract analysis.

Some significant heavy metal concentrations were observed in the San Miguel River at the Telluride site, where the mining and milling of a copper-lead-zinc ore is in progress. Principal among them are manganese, lead, and zinc. A portion of these are contributed by the tailings disposal area, but a variety of old mines and mine dumps, scattered throughout the watershed, also make a contribution. Equilibrium chemistry predicts smaller concentrations of these metals than observed in some groundwater and stream samples.

A total increase of 149 metric tons of dissolved solids was observed between the monitoring stations upstream and downstream from the active tailings pond during the months of October, November, May and June. The most likely source of these dissolved solids is the tailings transport water, and not a dissolution of salts from the tailings material. The ions with the largest observed concentrations in the stream were calcium, magnesium, sodium, and sulfate. These ions, plus chloride, also dominate the chemical makeup of the tailings transport water. The quality of tailings' percolate corresponds to that of the transport water very well.

SECTION II
RECOMMENDATIONS

Significant levels of nitrates were observed in the saturated paste extracts of the coal mine spoils investigated but it is not known if nitrates represent a significant water pollution potential. It is recommended that research into the origin, magnitude, and mobility of nitrates be persued.

The mechanisms by which heavy metals reach and maintain the concentrations observed in this study at the Telluride site deserves further investigation. Similar, unexplained observations have been made by other investigators.

A program should be undertaken, in which , a detailed survey of current and projected strip mining the the Upper Colorado River Basin is made. The location, geology, hydrology, and areal extent of each operation and projected operations should be inventoried. Where possible, saturated extract analyses of overburden samples should be made. The result would be a set of data, from which, the total salt load increase as a result of mining in the basin could be projected. Such a projection is needed to ascertain the significance of the problem so that an appropriate national priority can be established.

A mathematical model of the process of salt pickup from mine spoils, including the important geochemical and hydrological aspects, should be developed and verified. The model would be an efficient tool for determining salt loading as a function of time and for studying the effectiveness of various abatement procedures. Projections of salt loading on a watershed scale under different management and mine location alternatives could also be obtained from the model.

SECTION III
INTRODUCTION

BACKGROUND

The basic underpinning of mankind's struggle for survival and his ability to attain an acceptable standard of living resides directly in two fundamental activities: the agricultural and mineral industries. Society's dependence on the products of agriculture is well understood and obvious relative to that of the mining industry. Rarely is one reminded that the mining industry provides the mineral fertilizers essential to the production of the food and fiber so readily associated with the agricultural industry. The transformation of the raw products of mining is, often, so drastic that society does not readily recognize or appreciate that mining is the first essential step in the transmission of electricity, the construction of railroads, the production of concrete, the maintenance of potable water supplies, the processing of food, the fabrication of dental equipment and televisions, and a host of other activities. The electrical energy used to heat and operate factories and homes bears no resemblance to the coal from which it was produced. Nevertheless, raw fuels, metals, and nonmetals, the value of which comprises only 3 percent of the Gross National Product, have a direct impact on 40 percent of the national economy and an indirect impact on an additional 35 percent.

Since mining is an extractive industry, the potential for adversely affecting land and water utilization by other industries, agriculture, and municipalities is large. For example, numerous cases of water quality degradation caused by the production of mineral acids and sediment from strip-mine spoils in the eastern United States can be found. Land use is effected by the removal of vegetation and top soil, the exposure of toxic geologic materials, the creation of unstable slopes, erosion, and the change in aesthetic value. Many, if not most, of these potential

side effects of mining have been largely ignored by the industry and society, alike, until recent years. The intrinsic importance of mining and the recognition of environmental quality as an essential component in the social value system, now call for an appropriate balance between economic mining and resource conservation and protection. Responsible elements of society and industry have responded as evidenced by the research and technology now being applied to problems associated with mining in the eastern portion of the nation.

There exists relatively little documentation concerning potential land use and water quality problems associated with mining in the western states. Most of the western states receive much less precipitation than those located in the East and Midwest, and therefore, the effect of mining activity on the quantity and quality of water is a highly important consideration. Impairment of water quality in western rivers may have a direct economic impact on downstream users. This is particularly true of the Colorado River and its tributaries in which salinity has reached levels of national and international concern. The seven basin states sharing the water resources of the Colorado River and the Environmental Protection Agency have adopted a non-degradation policy designed to maintain the salinity in the lower basin at, or below, the current level. Without a basin-wide salinity control program, it is estimated that California, alone, will incur annual damages of $40 million by the year 2000.

Other potential problems associated with large scale mining in the west include the effect on stream biota, release of heavy metals or other toxic elements to the receiving waters, sediment production, and the change in the surface and subsurface hydrologic characteristics of the watershed. All of the above aspects remain less than adequately researched, and undoubtedly, many of them will be found to be insignificant. Even methods for revegetation of strip mine spoils and tailings disposal areas in the arid and semi-arid west have not been developed to the point of routine application; notwithstanding the significant progress that

has been made.

Water pollution potential, land use, revegetation, reclamation, erosion, slope stability, etc. are all mutually inter-dependent variables. Furthermore, they are functions of the geologic, hydrologic, and meteorologic environment, and it is only through a thorough understanding of the physical and chemical characteristics of the spoil materials, the surface and subsurface hydrology, and the meteorology that rational conclusions and recommendations can be drawn.

PURPOSE AND SCOPE

The purpose of this study was to identify potential water quality problems associated with the runoff and percolation through mine spoils at selected sites in the Upper Colorado River Basin, and to provide a quantitative description of the interactions among geological, chemical, hydrological, and meteorological variables influencing potential water quality degradation at these sites. Three sites were selected: the Navajo Mine near Fruitland, New Mexico; the Edna Mine near Oak Creek, Colorado; and the Idarado Mine near Telluride, Colorado. The first two sites are located on the spoils produced by surface coal mining operations and the third is located on the mill tailings associated with the mining of a lead-zinc-copper ore. The hydrology, geology, and topography at each site are significantly different, providing a wide range of conditions for study and a partial basis for generalization of results.

The approach used to assess the water pollution potential of the spoils is based on the premise that the potential is directly related to the availability of both water and pollutants within the spoil banks. Spoil samples were collected and analyzed in the laboratory and leaching tests were made. These data are indicative of the quantity and type of contaminants that are readily available in the spoil banks. Estimates of the quantity of water required to leach the contaminants were made from the column tests. Analyses of available hydrologic and meteorologic data

were conducted and related to the quantities of water available for leaching the spoils.

At the Edna and Telluride sites, water quality monitoring stations were established in the receiving streams and groundwater aquifers to identify the type of contamination that occurs and to measure the degree of degradation. Samples were collected monthly and subjected to chemical analyses. In addition, several gaging stations were constructed and calibrated to provide surface-water discharge data which were used in the interpretation of observed water quality changes and to calculate contaminant discharges. The in-stream data are correlated with the chemical analysis of the spoils to show their relationship. Limitations of time and budget made it necessary to restrict the scope of the investigation at the Navajo site to making a limited number of infiltration tests and analyses of spoil and overburden.

The data and analyses outlined above provide a rather detailed description of the current and potential water quality impairment attributable to the spoils studied. The influence and relationships identified among several geological, chemical, hydrological, and meteorological characteristics constitute the first important step toward an in-depth comprehension of the systems under consideration, notwithstanding several observations that are not well understood at this time. The necessarily limited scope of this one-year study prevented the in-depth investigation of several potentially important observations and the refinement of many measurements and estimates to the degree desirable. Continuing study of several of these aspects is under way by the authors and other investigators.

SECTION IV
GEOLOGIC-HYDROLOGIC PERSPECTIVE

NAVAJO MINE

The Navajo Mine is located in the northwest corner of New Mexico immediately south of the village of Fruitland (figure 1). The mine is a surface coal mine operation situated on an outcrop of the Fruitland formation near the western edge of the San Juan Basin in San Juan County. The Fruitland formation is an Upper Cretaceous sequence of interbedded sandstone, siltstone, shale, carbonaceous shales and sandstones, and coal (Fassett and Hinds,[1] 1971). The interbedded units are almost entirely discontinuous, with most individual beds pinching out in a matter of a few hundred meters. The exceptions are the coal beds which are continuous over several miles in some instances.

The outcrop on which the mine was started is near the western edge of the Hogback Monocline, which dips to the east at about 3 percent. Thus, the coal beds, some of which have been exposed by erosion at the outcrop, become progressively deeper to the east. The Kirtland shale, composed of upper and lower units of gray shale separated by the Farmington sandstone member, conformably overlies the Fruitland rocks and forms additional overburden to the east of the present mining operations. Immediately to the west of the mine, the Pictured Cliff sandstone formation outcrops below the Fruitland formation. This sandstone, characterized by one or more massive sandstone beds in the upper portion, is in conformable contact with the Fruitland sequence. The Pictured Cliff sandstone is underlain by the Lewis shale, a marine deposit consisting of light-, to dark-grey, to black shales with interbedded sandstone and silty limestones.

The Pictured Cliffs sandstone is the result of shallow-water and beach-sand deposits formed by the final retreat from the San Juan Basin of a

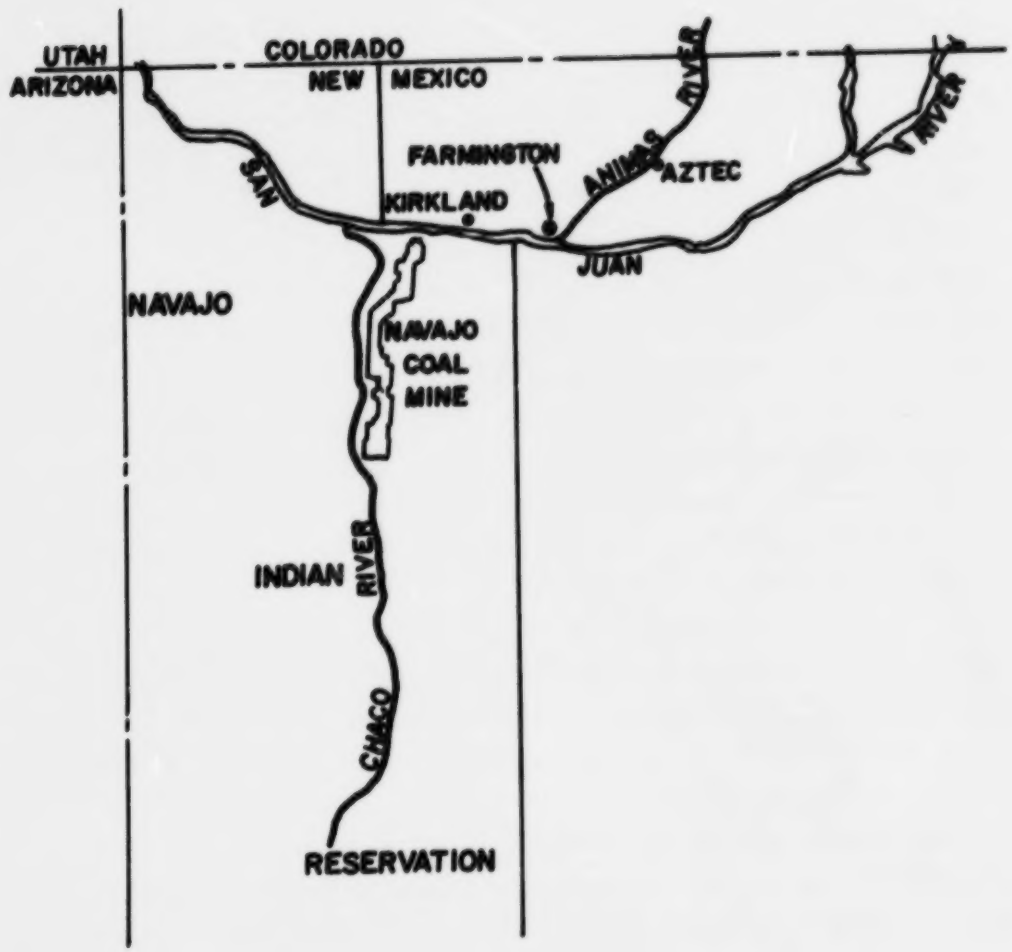


Figure 1. Location of the Navajo Mine.

Cretaceous epeiric sea that extended from the Arctic Ocean to the Gulf of Mexico in late Cretaceous time. This epeiric sea divided the North American continent into eastern and western land masses and covered most of the Rocky Mountain and Great Plains states, as well as portions of the Gulf states. Coastal swamp, river, flood plain and lake deposits were laid down on top of the Pictured Cliffs as the sea regressed. These materials now form the Fruitland formation. Vegetal matter accumulated in the shoreline swamps and was subsequently covered by river deposits. The accumulated vegetal matter comprises the coal beds in the Fruitland rocks.

The climate at the Navajo Mine, at an altitude of 1550 m (5100 ft), is arid with an average annual precipitation of 17 cm. The mean monthly temperature in January is -1°C and during July is 25°C. The mean daily minimum and maximum temperatures in January are -8°C and 6°C, respectively. In July the mean daily minimum and maximum temperatures are 16°C and 33°C, respectively. The estimated average annual potential evapotranspiration by grasses is 103 cm; a quantity which exceeds the average annual precipitation by 86 cm.

Groundwater occurrence in the mined area is erratic. Small bodies of perched groundwater are encountered in the Fruitland rocks. The small quantities and erratic occurrence are consistent with the local and discontinuous beds of this formation. Unconfined groundwater occurs, again in small quantities, in the Kirtland shale to the east. The only significant groundwater reservoir (in terms of size) is found in the Pictured Cliffs sandstone below the Fruitland formation. Water quality in this reservoir was extremely poor prior to mining. Small, local accumulations of groundwater sometimes exist in shallow alluvial deposits associated with the arroyos in the area.

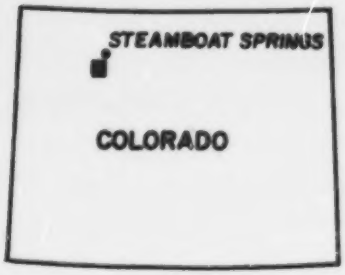
The major drainage feature in the northwest corner of New Mexico is the San Juan River which flows westward at the north end of the mined area (see figure 1). Surface drainage from the mine lease is toward the west

through the Chinde Wash, Cottonwood Arroyo, and Pinabete Arroyo to the Chaco River. The Chaco River flows north along the west side of the lease area and into the San Juan River. The mine lease is located within the eastern limb of the Chaco River watershed which covers some 1.13×10^6 ha (4350 square miles; Rabinowitz and Billings,[2] 1973). The mean annual discharge of the Chaco River at the confluence with the San Juan River is estimated to be approximately 2.22×10^8 m^3 (1.8×10^4 acre-feet) or nearly 2 cm (0.8 inches) over the entire watershed. The total area within the mine lease boundary is approximately 1.3×10^4 ha (32,000 acres), or slightly over 1 percent of the Chaco River watershed.

EDNA MINE SITE

The Edna Mine is located on the extreme southeast edge of Twenty Mile Park just northwest of Oak Creek, Colorado (figure 2). Coal is extracted from the Wadge seam in the Williams Fork formation of the Mesa Verde group. The Williams Fork unit is Upper Cretaceous in age but is somewhat older than the Upper Cretaceous Fruitland formation at the Navajo Mine. The Lewis shale, which lies beneath the Pictured Cliffs unit in the San Juan Basin, conformably overlies the Williams Fork unit in northwest Colorado. At the Edna Mine, the Lewis shale has been eroded away, and the overburden materials are of the Williams Fork formation. Bass, et al.[3] (1955) describe the lower unit of the Williams Fork, in which the Wadge seam is located, as consisting chiefly of shale, thin sandstone beds and sandy shale.

Present mining operations are being carried out on the eastern limb of the Argo syncline (Cammpbell,[4] 1923). The dip of the formations is toward the west at approximately 10 percent. The topographic surface strikes to northeast parallel to Trout Creek and, also, dips to the west toward the stream at about 10 percent. Trout Creek flows generally north at the foot of the mined slope. The coal is exposed by stripping the overburden, resulting in a series of spoil ridges oriented parallel to the strike of the slope. The spoils are presently being regraded



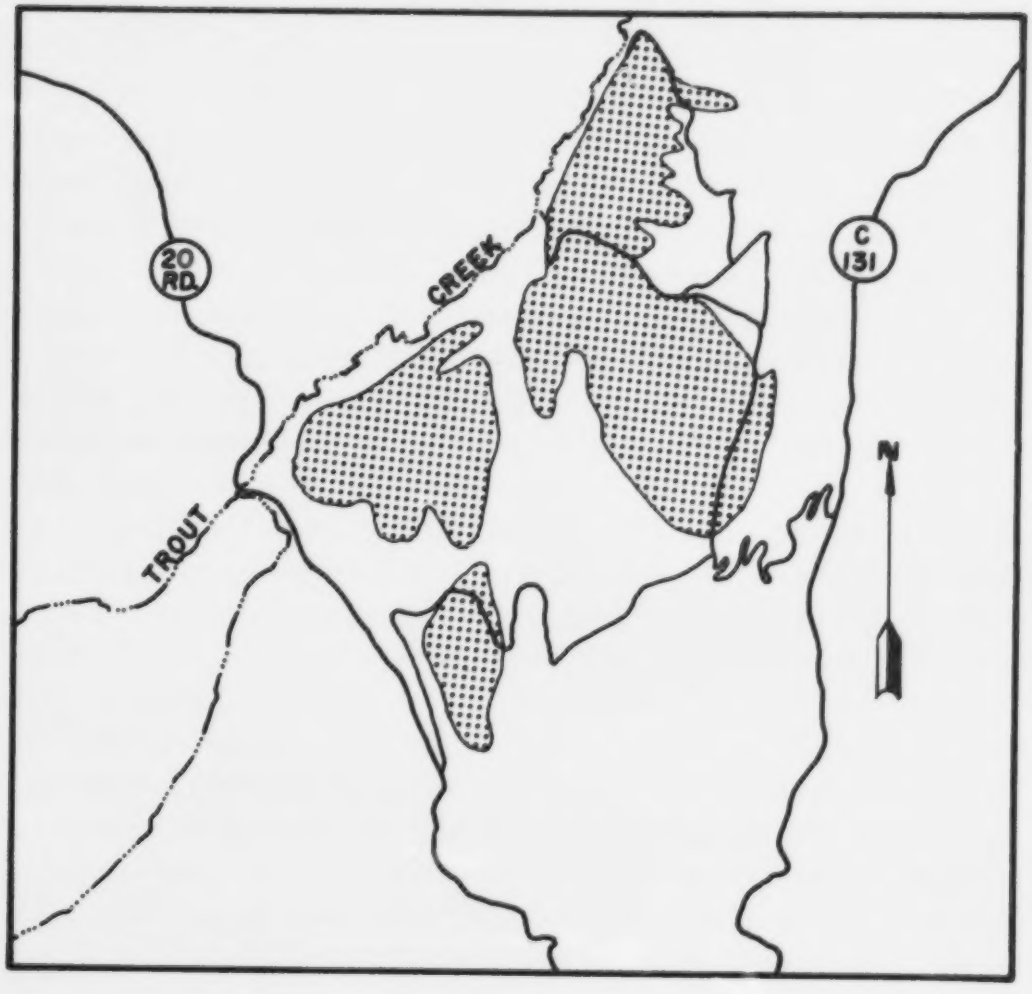


Figure 2. Location of the Edna Mine.

to approximate original contour.

The climate at the Edna Mine contrasts markedly with that at the Navajo Mine. The Edna spoils are located between the elevations of 2160 m (7100 feet) and 2380 m (7800 feet) above mean sea level. The mean annual precipitation at the mine is estimated to be 51 cm; about one-half of which occurs in the form of snow. The coldest month is January and the warmest is July. The estimated annual potential evapotranspiration by grasses at the Edna Mine is 93 cm. The potential evapotranspiration exceeds the precipitation by some 42 cm on an average annual basis.

Trout Creek, which flows generally north at the foot of the mined slope, is the major surface drainage in the area. The stream has eroded a shallow canyon in the Williams Fork rocks as evidenced by nearly vertical outcrops of the formation on both sides of the stream below the spoils. Shallow alluvium occurs along the stream bed and forms a local alluvial aquifer. The lateral extent of this aquifer, in directions perpendicular to the stream, is limited by the "bed rock" outcrops formed by the stream erosion. Groundwater occurrence in the undisturbed Williams Fork is limited to local fracture storage as evidenced by an almost dry mining operation.

The Trout Creek watershed, above and including the Edna Mine, is approximately 1.1×10^4 ha (43 square miles). The mean annual discharge of Trout Creek, just downstream of the mine, is estimated at 2.8×10^7 m^3 (2.3×10^4 acre-feet), or nearly 26 cm (10 inches) over the portion of the watershed above the mine. The total disturbed area at the Edna Mine is approximately 597 ha (1475 acres), or slightly more than 4 percent of the total watershed area upstream of the mine.

IDARADO MINE SITE

The Idarado Mine is an underground mine in the San Juan Mountains near the head waters of the San Miguel at Telluride, Colorado (figure 3).

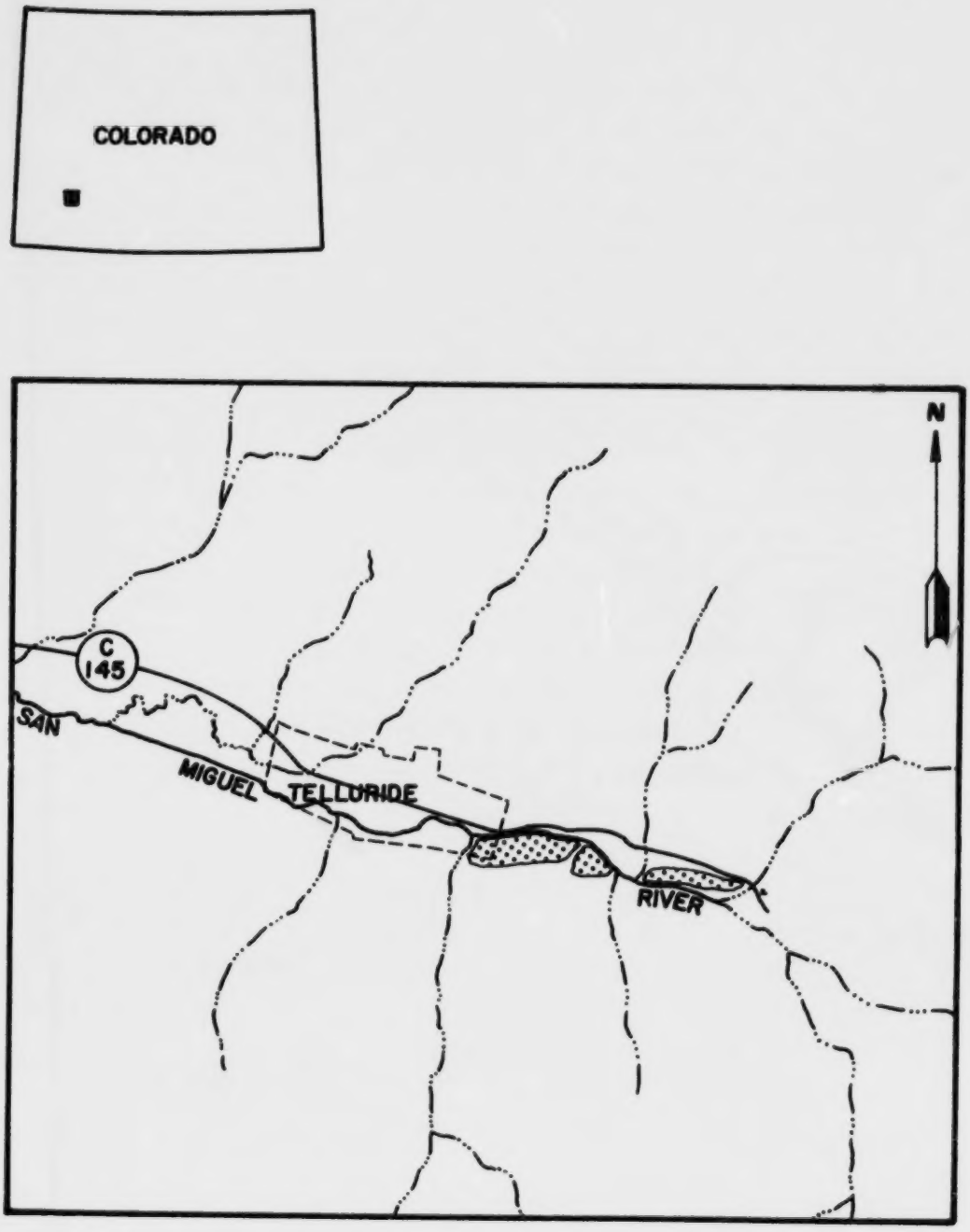


Figure 3. Location of the Idarado Mine.

The San Juan Mountains form the southwest limit of the Colorado mineral belt; a long, narrow corridor that extends diagonally across the mountains from Boulder County to southwestern Colorado. The belt is characterized by porphyries and associated ore deposits throughout its length (Tweto and Sims[5], 1963). The porphyry materials are, largely, Tertiary in age, being formed during the Laramide orogeny by intrusion along a zone of Precambrian shearing that forms the limits of the mineral belt. The Laramide orogeny occurred in Late Cretaceous and Early Tertiary time and simultaneously with the retreat of the Cretaceous epeiric sea, with which the formation of the sedimentary Fruitland rocks in New Mexico and the Mesa Verde group in Colorado are associated.

The San Juan Mountains are not the direct result of the Laramide mountain building period, however. Rather, they were formed in Late Tertiary time by extensive volcanic eruptions after the Laramide orogeny had drawn to a close. It was at this time that the valuable ore deposits were formed. The present day sharp peaks, deep canyons, shear cliffs, and steep-walled valleys are the result of subsequent glaciation that occurred during the Pleistocene. Ore deposits in the Telluride District normally occur in chimneys, breccia veins, and fissure veins in the volcanic rocks near the edge of the Silverton caldera.

Early mining activity centered around the extraction of precious metals from the oxidized zones of the veins near their outcrops. Recoverable base metals became increasingly important with depth, and today, profitable operations depend, almost entirely, on base metal production. The Idarado ore is composed mainly of galena, chalcopyrite and sphalerite, from which lead, copper and zinc are extracted. The mine consists of a complex system of interconnected drifts, stopes and shafts resulting from a consolidation of several old mines dating back 100 years. The lowest level of the mine is some 885 m (2900 feet) below ground surface. A variety of stopes, drifts, tunnels, and natural fractures intersect the surface, permitting significant quantities of runoff to enter the mine workings. Portions of the mine drainage are discharged into small

streams, immediately tributary to the San Miguel River.

An average of 1.5×10^6 kg (1650 tons) of ore are processed each day at the Pandora Mill on the San Miguel River at Telluride. Mill tailings in the amount of 1.41×10^6 kg (1550 tons) are transported in 4.2×10^3 m^3 (1.49×10^5 ft^3) of water to tailings ponds each day. The tailings ponds are located adjacent to the river where the solids in the slurry have formed large spoil banks. The transport water and incident precipitation evaporates and percolates downward through the spoils. Over the years, six separate tailings ponds have been formed which are, now, largely contiguous with one another.

The Idarado study area is located at an elevation of 2740 m (9000 feet) in a glacial cirque. The site is surrounded on three sides by towering mountains and sheer cliffs rising to elevations of more than 4000 m (13,000 feet). The mean monthly temperature during January, the coldest month, is -6°C, and the warmest month, July, has a mean temperature of 15°C. The mean annual precipitation is 61 cm (24 inches) at Telluride, approximately 50 percent of which occurs as snow. The mean annual snowfall in the mountains immediately surrounding Telluride is 5.1 m (200 inches). The potential evapotranspiration for grasses at Telluride is calculated to be 84 cm (33 inches).

The major drainage features are the San Miguel River and its tributaries: Bridal Veil Creek, Marshal Creek, Bear Creek, and Ingram Creek. All of these tributaries enter the river within or above the study area. The mean annual discharge of the San MIguel at Telluride is estimated to be 4.56×10^7 m^3 (3.7×10^4 acre-feet) from a watershed of 1.1×10^4 ha (43 square miles). This is equivalent to a runoff of 42 cm (16.5 inches) over the entire watershed above Telluride. The tailings pond spoils have a surface area of approximately 43 ha (85 acres), or only 0.3 percent of the upstream watershed area.

SECTION V
FIELD AND LABORATORY INVESTIGATIONS

FIELD STUDIES

This section contains a description of the field experiments and procedures used at each site. These include water quality sampling, spoil sampling, infiltration tests, discharge determinations, and groundwater observation well installation. Also included are descriptions of the sample designation codes and locations.

Water Quality Monitoring

Eight surface water quality monitoring stations were established at the Edna site. Five of these points are in-stream stations on Trout Creek, and three were specifically located to sample water directly from the mined area. The locations of the sampling points and their designations are shown in figure 4. Station C1 is located in Trout Creek upstream of all coal mining activity in the area, and thus, provides baseline data to which downstream water quality can be compared. Station C2 is also located in Trout Creek, 1.9 km downstream of C1. One small-scale underground coal mine is located near the stream between points C1 and C2.

Water which has percolated through and over the older, "knock off graded" spoils to the is sampled at station C3 where it collects behind and highwall of the box cut at the foot of the mined slope. There is a spill point, over which, water flows into the stream. Sample station C4 is on Trout Creek below the southwest mined area but above the northeast portion. Two small tributary drainage ways join Trout Creek between stations C2 and C4; both on the mine spoil side of the stream. Station C5 is on a small drainage way, leading directly from the northeast spoil area. This area has been regraded to the approximate original contour. Point C6 was established on the stream immediately above an irrigation

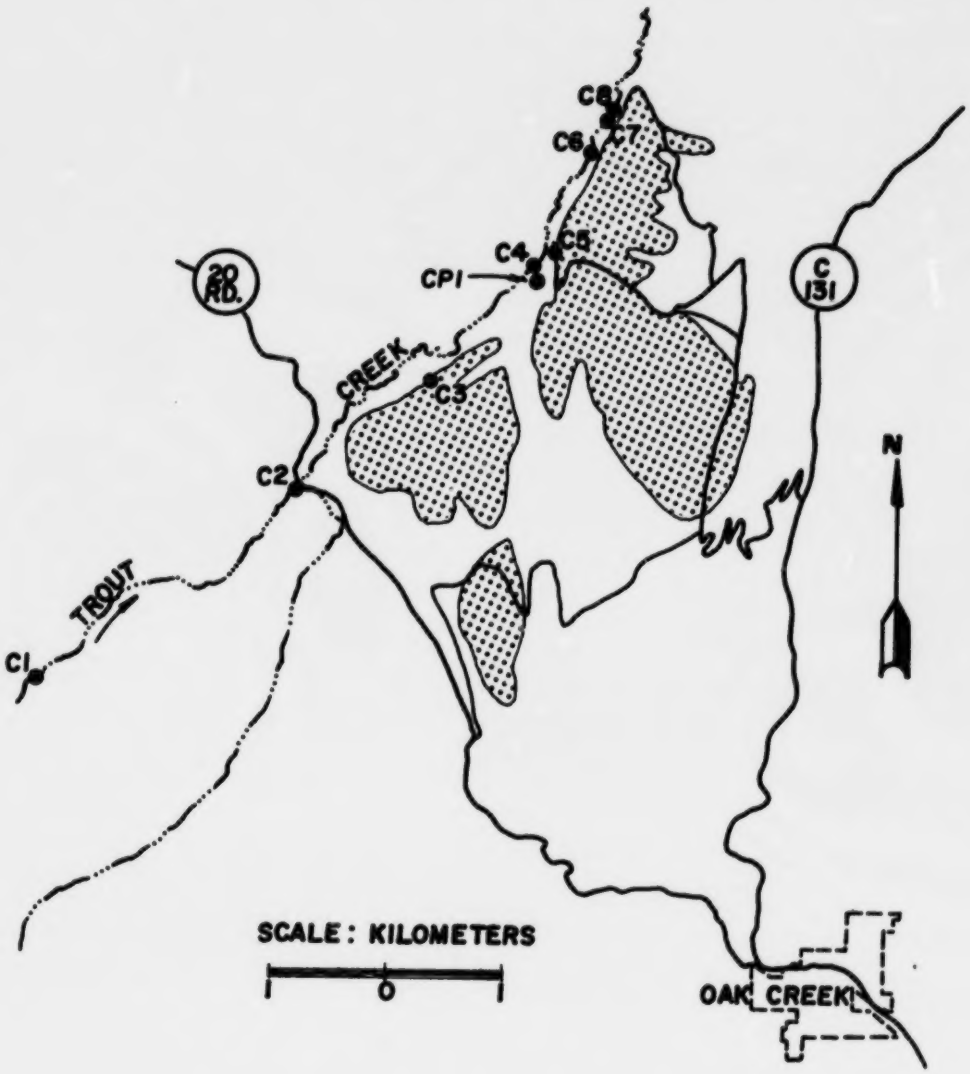


Figure 4. Edna Mine spoils, Trout Creek, and water quality monitoring stations.

diversion point. Groundwater seepage from the mine was sampled at station C7 on the seepage face formed by the intersection of the water table with the stream bank. In-stream station C8 was established in an attempt to detect differences in water quality caused by the groundwater influent between stations C6 and C8. Groundwater samples were collected at an observation well and designated CP1. The location of this well is also shown in figure 4.

No water quality monitoring program was established at the Navajo site because surface flows are intermittent and groundwater in significant quantites was too deep to study within the scope of this project. There are a few data on water quality, available from other sources, that will be used later in this report.

During the first month of sampling at the Idarado site, a total of 22 water samples were collected. Based on the analysis of these samples, the number of sampling stations was reduced to thirteen; eleven surface stations and two groundwater stations. The locations of the first nine surface water sampling points are designated by T1 through T9 and are shown on the map of figure 5. Station T10 is located on the San Miguel at the confluence of the South Fork, several kilometers downstream of Telluride. Station T11 is on the river at Placerville, Colorado near the U. S. Geological Survey stream gaging station.

Station T1 is located just below the confluence of Ingram and Bridal Veil Creeks above all Idarado operations on the stream. Many old mine workings exist above the T1 station, however, and the water quality cannot be considered representative of that which would exist in the total absence of mining activity. Samples collected at T2 are mine drainage samples. Station T3, on Marshal Creek, also samples mine drainage after dilution with normal stream water. Stations T4, T7, T8, and T9 are located on the river. Station T5 is on Bear Creek, and water from this sampling point is used as the datum for comparing water quality. Seepage through the tailings pond spoils was monitored at station T6 from a drain pipe

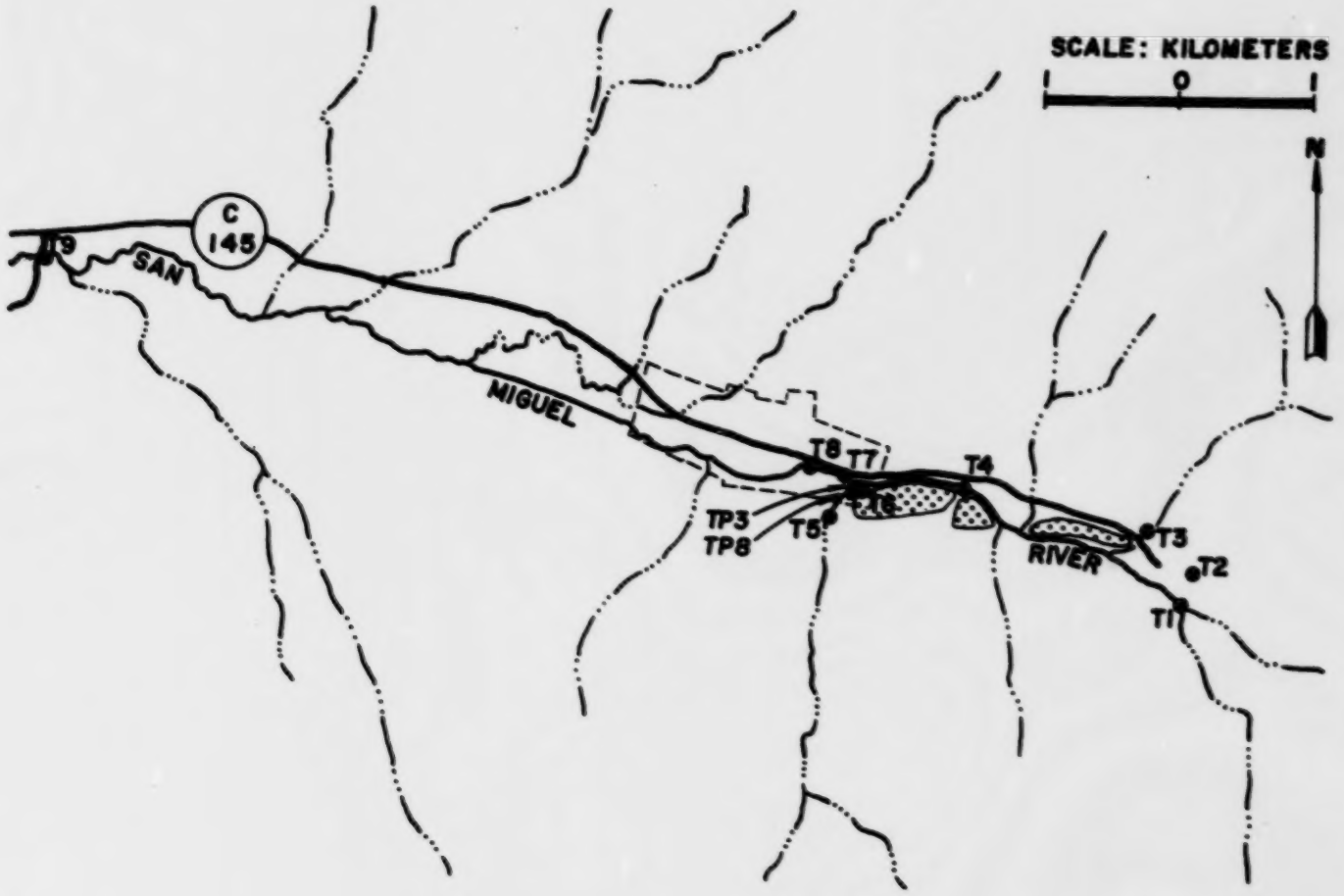


Figure 5. Idarado Mine, San Miguel River and tributaries, and water quality monitoring stations.

and at two observation well stations; TP3 and TP8.

Beginning in October, 1973, samples were collected monthly at the above described stations. These samples were treated and analyzed in accordance with EPA procedures. Some difficulty with sampling was experienced from time to time. During the winter months, the water in piezometers was often frozen, making it impossible to collect a sample. Thick ice cover on the streams made it necessary to collect samples through holes, chopped in the ice with an ax. It was sometimes discovered that the water was frozen all the way to the stream bed, in which case it was necessary to move downstream a short distance and repeat the attempt to find water. It was not uncommon for water samples to freeze in a short time following their extraction. Nevertheless, a reasonably complete set of water quality data for the period October 1, 1973 through July 1, 1974, was generated for both the Edna and Idarado study sites.

Discharge Monitoring

Three discharge measuring stations were established at the Edna site. The upstream station on Trout Creek was set up at quality monitoring station C2 (figure 4) above the portion of the watershed in which the spoils are located. The stream discharge was measured by determining the velocity distribution in the cross-section with a current meter. The corresponding water stage was noted from a staff gage that was constructed at a convenient location on the cross-section. These data, repeated at different stages, together with measurements of the dimensions of the flow section permitted the construction of an approximate stage-discharge relationship. A similar procedure was used to estimate the discharge at the C6 location (figure 4) just above an irrigation diversion point. The discharge from the boxcut at station C3 was also measured. This was accomplished by installing a 30 cm (12 inch) Parshall flume at the spill point.

Procedures, similar to those used at the Edna site, were used to estimate

the discharges at several locations at the Idarado site. These include the mine drainage at station T2 (figure 5), Marshal Creek (T3), Bear Creek (T5) and the San Miguel River at two locations (T4 and T8). The appropriate stage measurements at each station were taken monthly at the same time water quality samples were obtained. Difficulties with thick ice and deep snows made it impossible to obtain a complete record of discharges at some locations, and also influenced the accuracy of the discharge estimates. The significance of both the discharge measurements and their inherent errors are discussed in a subsequent section of this report.

Groundwater Monitoring

Several observation wells were installed at strategic locations at both the Edna and Idarado sites. The wells consist of a 3.2 cm (1¼ inch) galvanized pipe casing with a screened well point (sand point) on the lower end. Several feet of pipe were extended above the ground surface for easy location and access in deep snow. The pipe and well points were installed in holes augered by a trailer-mounted boring unit. The annular space between the hole wall and the pipe was filled with available soil and cuttings. No attempt was made to completely seal the annulus with an impermeable material. Thus, the well points act as observation wells rather than piezometers.

Eleven wells were installed in the alluvium adjacent to Trout Creek between the stream and the toe of the spoil banks. The wells were installed in areas where preliminary observations indicated groundwater influent from the mined area. Eight wells were installed near the active tailings pond at the Idarado site, and three wells already existing in the tailings were incorporated into the network. The locations of the wells were determined by a survey and plotted on appropriate maps. Arbitrary elevation datum points were established at both sites, and the elevations (relative to the datum points) of each observation well were determined.

The depth to water in the observation wells was measured monthly. These data were then converted to water table elevations from which water table maps showing the gradient and direction of groundwater movement were prepared. The water table maps are presented in a subsequent section of this report.

Infiltration Tests

Ten infiltration tests were performed in this study; four on the Edna site, four on the Navajo site, and two on the Idarado site. Infiltration was measured using the well known cylinder infiltrometer method. Open ended cylinders, approximately 36 cm (14 inches) in diameter and 46 cm (18 inches) long, were driven into the material to be tested to a depth of at least 15 cm. A berm was constructed around the cylinder at a distance of approximately 20 cm (8 inches). A staff gage was installed inside the cylinder, and a sheet of plastic was placed so that the soil surface and the inside surface of the cylinder were completely covered. Water was poured into the cylinder on the plastic to a depth of about 15 cm. When all was in readiness, the plastic sheet was slowly and carefully removed, allowing infiltration to begin. Simultaneously, the moat around the outside of the cylinder was filled with water. The depth of water in the infiltrometer was recorded as a function of time to obtain the cumulative infiltration curve.

At the Edna and Navajo sites, infiltration curves were measured for both graded spoils and undisturbed soil. Revegetated tailings and fresh tailings were tested at the Idarado site. Infiltration was allowed to proceed until the intake rate appeared to be constant. The final constant rate can be taken as an approximate measure of the hydraulic conductivity of the materials in an undisturbed state. Downward and lateral spreading of the wetted volume by capillary pressure gradients that still exist, even after long periods of time, cause the hydraulic conductivity estimated by this method to be somewhat high. It is believed that this disadvantage is far outweighed by the advantages of making the tests in the

field on relatively undisturbed material, however.

Spoil Sampling

Spoil samples to be used for physical and chemcial characterization were collected at eight locations of the Edna spoils. Samples were taken every 15 cm (6 inches) of depth from the surface to a depth of 120 cm at three locations on the extreme north end of the mined area (see figure 4). Samples from the up-slope limit of mining are denoted by NSI, from near mid-slope by NSII, and from the foot of the slope by NSIII. The depth interval for each sample is appended to the above location code. A similar procedure was used to collect and code samples in the spoils immediately east of station C4 in figure 4. These samples were given the code MSI, etc.. Samples from the older spoils south of station C3 in figure 4, were collected at two locations and given the designation SSI and SSII, appended with the appropriate depth interval.

In addition to the above samples, native soil was collected at intervals to a depth of a meter at one location. Also, a number of drill cuttings were sampled along the active highwall. This was accomplished by collecting a drill sample in every 3 m interval from the surface to the coal seam at four locations along the active high wall. These samples were subsequently composited by depth interval and designated as DC with the appropriate depth interval appended.

The approximate locations of the sampling sites on the Navajo Mine are indicated in figure 6. Samples designated by R-1 through R-6 were collected on an east-west line, traversing a series of ungraded spoil ridges ranging in age from June, 1973 to September, 1970. These samples are all surface samples. Sample R-1 is the youngest and R-6 the oldest spoil material in the three year time interval.

Overburden samples were collected on the high wall in the Hosteen Pit in approximate 1.5 m intervals from the surface to the top of the uppermost

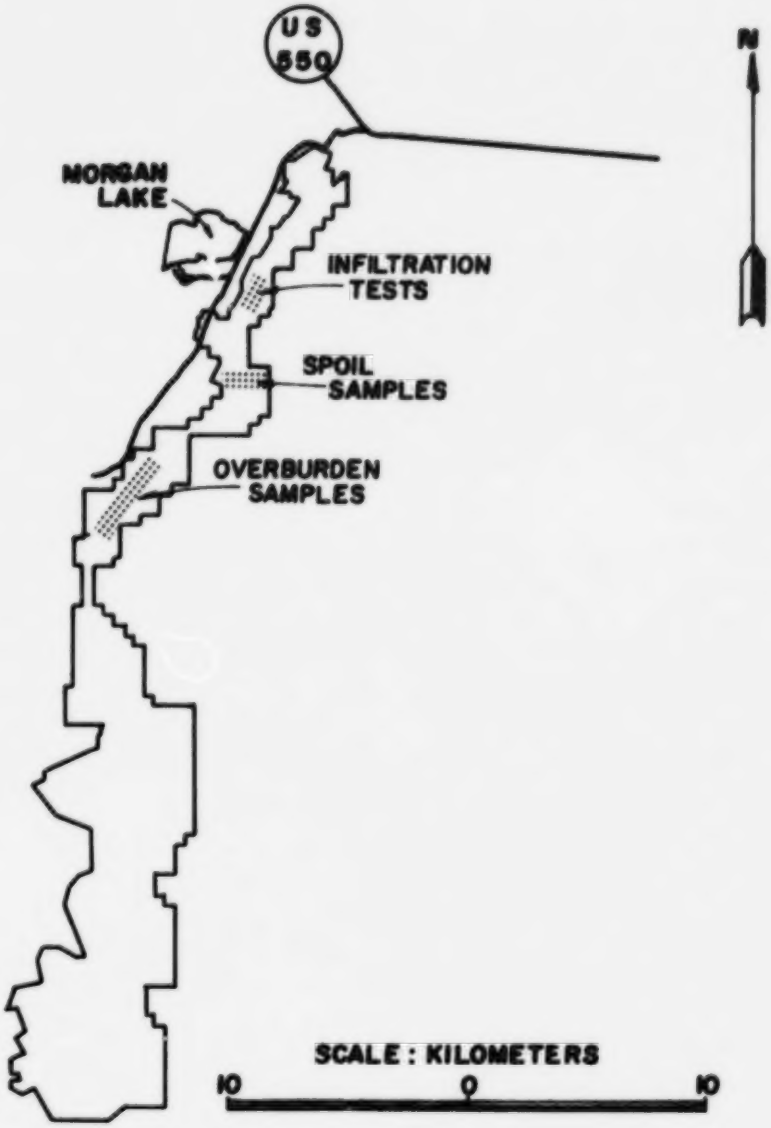


Figure 6. Approximate spoil sample locations at the Navajo Mine.

coal seam (No. 6 seam). Seams numbered 7 and 8, which normally occur above the No. 6 seam, are not present in the Hosteen Pit. A total of eleven overburden samples were collected in approximate 1.5 m intervals from the soil surface to the top of the No. 6 seam in the Barber Pit. At this location, seams No. 7 and 8 are present above the No. 6. Thus, the partings between the No. 8 and No. 7 seam and between the No. 7 and No. 6 seam were sampled. The material in the latter parting is the surface material after stripping.

Samples of the tailings at the Idarado site were collected from each of the six tailings ponds. A trailer-mounted boring unit was used to collect samples in 15 cm intervals over depths ranging from 1.5 m to 7 m. The most extensive areal distribution of sampling was conducted on tailings pond No. 6. Deep sampling was accomplished at ponds No. 1, 2, and 5. The first number in the sample code indicates from which pond the sample was extracted. The second set of numbers designates the depth interval.

LABORATORY STUDIES

A variety of laboratory tests and experiments were performed during the course of this study. These include water analysis, spoil sample analysis, and leaching experiments. The pertinent features of the experiments and procedures are described in the following paragraphs.

Water Analysis

Water samples were analyzed for: total acidity and alkalinity, total hardness, pH, specific conductance, suspended solids, total dissolved solids, total solids, and concentrations of aluminum, calcium, chloride, copper, dissolved iron, undissolved iron, total iron, potassium, magnesium, manganese, sodium, lead, sulfate, and zinc. These determinations were made on 22 water samples collected each month from the locations previously described. All samples were collected and treated in accordance

with the standard Environmental Protection Agency "Methods for Chemical Analysis of Water and Wastes" (U. S, Department of Interior,[6] 1970). Those analyses and sample treatment steps which were designated by this manual for completion within 24 hours after collection were accomplished in the field, and those which must be completed within seven days were accomplished immediately upon return to the laboratory. The samples for all other analyses were stored under the conditions stipulated in the manual. Usually, all analyses were completed within two months after collection.

Spoil Analysis

Based on the assumption that the minimum pollution potential of the spoils is best indicated by the quantities of water soluble cations and anions present, the saturated paste method was used to chemically characterize the spoils and overburden. It was recognized that such factors as weathering, microbial activity, acid formation, cation exchange capacity and nonequilibrium chemical reactions, among other factors, all influence the pollution potential of spoils in ways not characterized by the saturated paste method. Preliminary tests of leachate and surface water samples indicated, however, that the saturated paste analyses should account for the observed contaminants in these water samples. The expected correlation between the major constituents of the saturated pastes and those observed in field water samples was subsequently verified and will be discussed in a following section of this report.

The procedures used in the saturated paste method are described in detail by Hergert[7] (1971a). The sample is first completely dried and then the material is reduced in size to the point where it will pass a 2 mm (ten mesh) screen. The sample is saturated with distilled water, thoroughly mixed, and allowed to stand for 16 hours. The saturation percentage is determined on a portion of the sample by normal gravimetric techniques and the water is extracted from the remainder of the sample. The extract is then subjected to a variety of analyses for the chemical constituents. In this study, determinations of pH, specific conductance, calcium,

magnesium, sodium, potassium, carbonate, bi-carbonate, chloride, sulfate and nitrate were made. The concentrations of the ions are reported as mass of the particular species per million parts (by weight) of the extract.

Standard plant nutrient analyses were also performed on spoil and overburden samples. The details of the procedures are given by Hergert[8] (1971b). Concentrations reported in the plant nutrient analysis are reported as the mass of particular nutrient per million parts (by weight) of soil.

Leaching Experiments

Leaching tests were conducted with the two-fold purpose of estimating the total quantity of removable salts in the spoils and of determining the relationship between salt removal and water through-put volume. These tests were conducted by passing distilled water downward through columns of spoil, collecting the leachate in increments and measuring the specific conductance of each increment. The columns were approximately 30 cm long and the through-put rate was maintained equal to or below the hydraulic conductivity of the material in each column. A total of thirteen columns were subjected to leaching; 3 columns of Navajo Mine overburden, 3 columns of Edna Mine spoils, 3 columns of Edna drill cuttings and 4 columns of tailings from the Idarado site. A sample from each column was subjected to the saturated paste analysis to provide data on initial conditions.

SECTION VI
WATER QUALITY AND RELATION TO SPOIL CHARACTERISTICS

This section of the report is devoted to a presentation and discussion of the observed water quality and its relationship to the chemical characteristics of the spoils. Only the salient features of the data, pertinent to this discussion, have been extracted. Liberal use has been made of averages, summaries, and indicative parameters (such as total dissolved solids and specific conductance). Complete and detailed sets of data are tabulated in the appendices.

EDNA MINE SITE

Chemical Degradation

An example of the analysis of in-stream water samples on Trout Creek at the Edna site is presented in Table 1. Average results have little meaning, in this case, because of the variation from month to month over the sampling period and with location with respect to the spoil banks. The data in Table 1 is for the month of April, 1974, and for the sampling station immediately downstream of the spoils. Thus, Table 1 contains the data for the time and location at which the poorest water quality was observed. Public Health Service drinking water standards are also included in Table 1 for perspective. Note that soluble salts are apparently the major contaminants.

The observed water quality in the streams varied significantly with both location and time, particularly at the Edna site. Figure 7 shows the measured water quality (as indicated by specific conductance) profiles along Trout Creek at the foot of the mined slope. No significant water quality deterioration was observed between stations C1 and C2. There is no surface mining nor irrigated agricultural land between these stations.

Table 1. APRIL, 1974, WATER QUALITY ON TROUT CREEK.

Parameter	Trout Creek station C8	U. S. drinking water standards[a]
Acidity, mg $CaCO_3$/ℓ	<1	-
Alkalinity, mg $CaCO_3$/ℓ	120	-
Total hardness, mg/ℓ	470	-
Specific cond., μmohs/cm	894	-
Total dissolved solids, mg/ℓ	660	500
Suspended solids, mg/ℓ	6	-
Total solids, mg/ℓ	666	-
pH	7.8	8.0
Aluminum, mg/ℓ	<0.5	-
Calcium, mg/ℓ	210	-
Chloride, mg/ℓ	1.9	250
Copper, mg/ℓ	<0.1	1.0
Dissolved iron, mg/ℓ	<0.05	0.3
Undissolved iron, mg/ℓ	-	-
Potassium, mg/ℓ	3	-
Magnesium, mg/ℓ	49	125
Manganese, mg/ℓ	0.04	0.05
Sodium, mg/ℓ	17	-
Lead, mg/ℓ	<0.14	0.05
Sulfate, mg/ℓ	250	250
Zinc, mg/ℓ	0.017	5

[a]U. S. Public Health Service (1962).

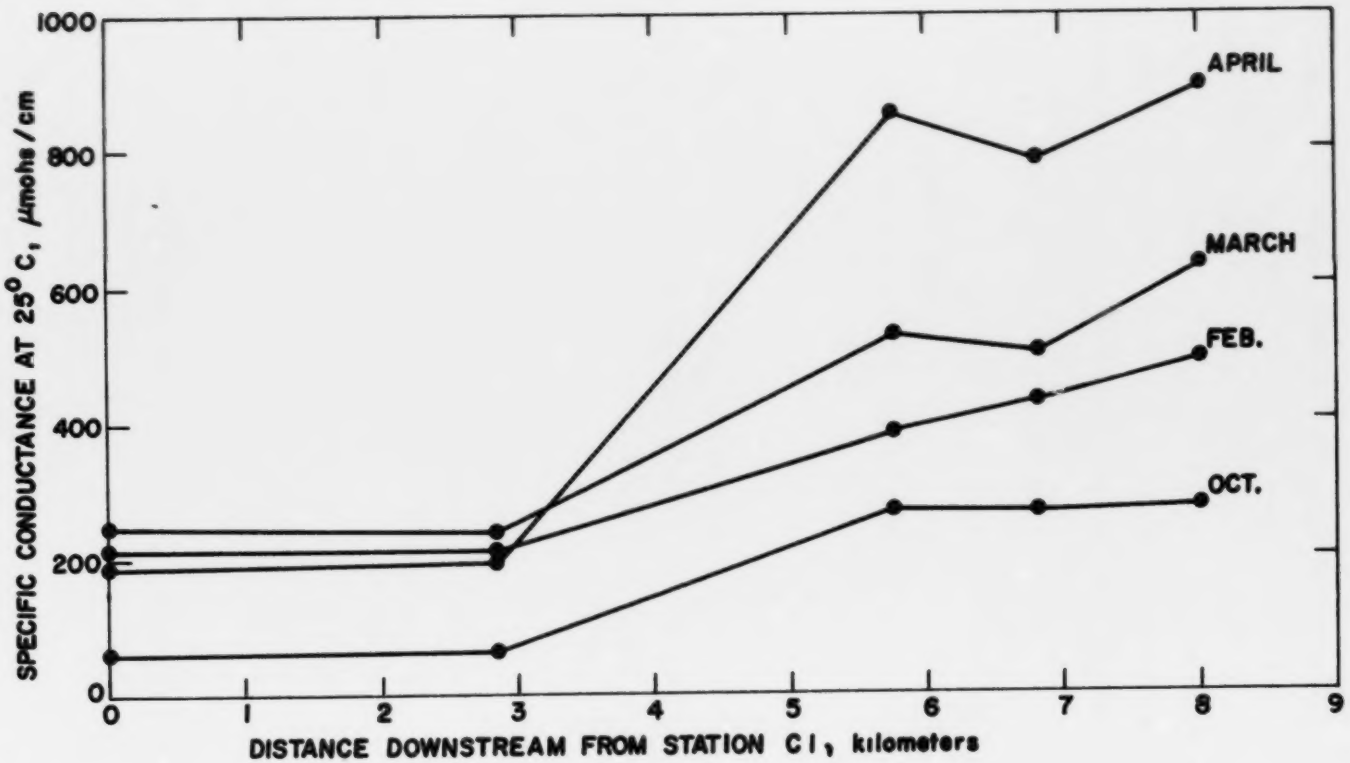


Figure 7. Specific conductance profiles on an eight kilometer reach of Trout Creek.

A very pronounced increase in conductivity occurs between stations C2 and C4, however. Surface and subsurface flows from the inactive spoil area directly south of station C3 and from irrigated meadows on the northwest side of the stream enter Trout Creek between stations C2 and C4. An additional increase in specific conductance was observed in the reach of stream between stations C4 (5.8 km downstream of C1) and station C8 (8 km downstream of C1). There are relatively fresh spoils immediately east of this reach (see figure 4), and irrigated meadows to the west.

It is noted from figure 7 that the specific conductance increases by a factor greater than two in the reach of stream investigated, and that the relative increase becomes larger through the winter and early spring. These results are more apparent in figure 8 which shows the specific conductance at the upstream station C2 and at the downstream station C8 plotted as functions of time. The conductivity at C8 exhibits a gradual increase between October and January, reflecting an increased fraction of relatively poor quality groundwater during these months of nearly base flow. The specific conductance of the groundwater at station C7 averaged 4105 μ mohs/cm for the nine month period.

The more pronounced increase in conductivity evident from January to March is attributed to an even larger groundwater contribution, relative to the surface water, as the surface water sources froze in the upper reaches of the watershed. Discharge measurements at station C2 indicate a significant reduction of the influx of dilution water from above the study area during February and March and, presumably, during January. The discharge at stations C2 and C3 are presented in Table 2.

Figure 8 shows that the specific conductance peaked in April and declined sharply in May and June. This is a reflection of an increase in surface and subsurface inflows from the study area relative to the quantity of water from the upper reaches of the watershed. This is evident in Table 2 which shows that, during the first week of April, when the samples

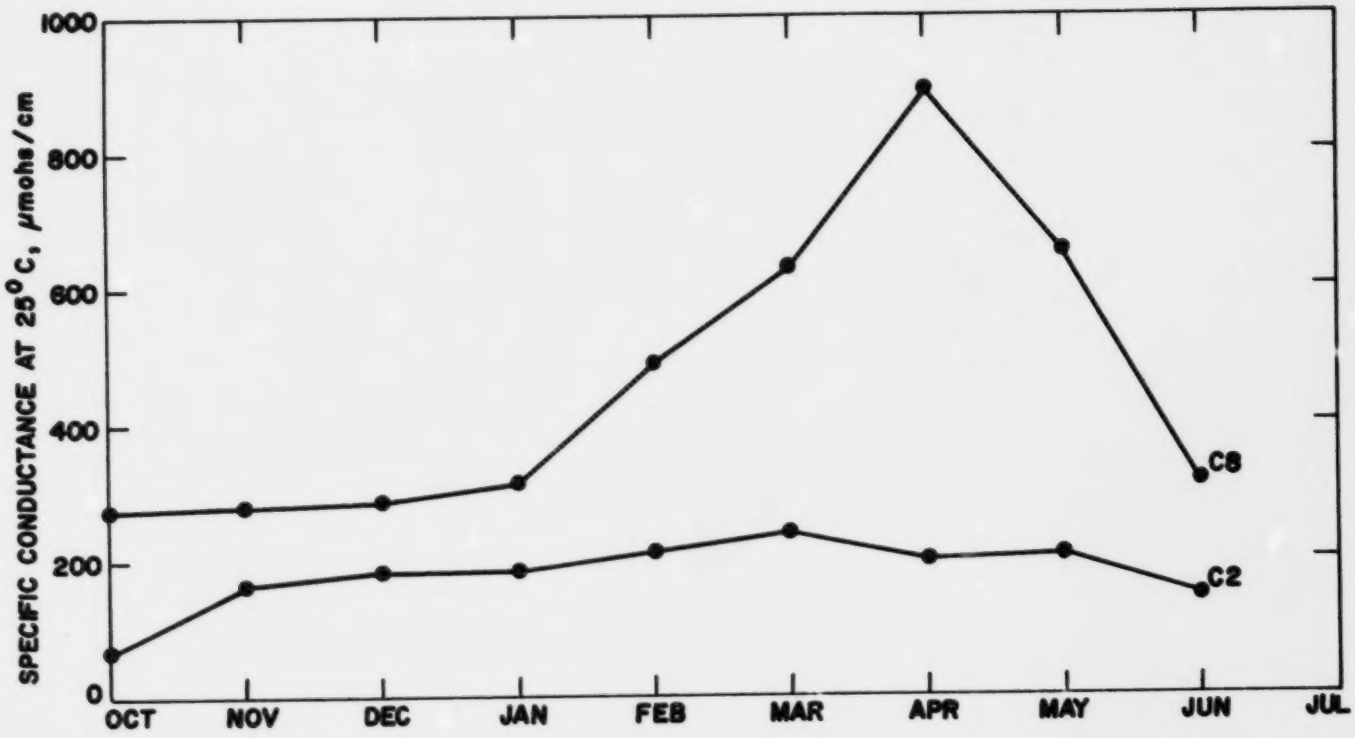


Figure 8. Specific conductance on Trout Creek for a nine month period.

Table 2. DISCHARGE AND SPECIFIC CONDUCTANCE AT STATIONS C2 & C3.

Time	Station C2			Station C3		
	Gage, cm	Discharge, m^3/sec	EC[a], µmohs/cm	Gage, cm	Discharge, m^3/sec	EC[a], µmohs/cm
Oct,1973	15.0	0.37	65	-	-	2450
Nov	14.0	0.31	164	4.6	0.006	2580
Dec	18.5	0.56	187	4.3	0.006	2510
Jan,1974	-	-	187	4.6	0.006	2350
Feb	12.0	0.22	211	4.3	0.006	2200
Mar	13.0	0.26	240	4.9	0.007	2130
Apr	13.0	0.26	200	10.7	0.023	1890
May	53.5	4.45	209	>34.2	>0.134	2450
Jun	58.0	5.32	147	9.8	0.020	2400

[a]Specific conductance at 25°C.

were collected, the stream flow at station C2 remained very close to the normal winter discharge, while the surface and subsurface runoff from the study area as indicated at C3, increased by a factor of three. Unfortunately, the Trout Creek gaging station at C6 was disrupted in January by ice, and a direct measure of the quantity of runoff from the watershed between stations C2 and C8 is not available. The data collected at station C3 is representative of both the timing and the quality of the mine discharge, however. The maximum observed runoff from the spoil area was observed in early May and, undoubtedly, the maximum contribution of salts from the study area occurred during the maximum runoff period. This is not reflected directly in figure 8, however, because of the dilution effect resulting from large discharges of better quality water observed at station C2 in May (Table 2).

The results presented above leave little doubt that water quality degradation occurs in the reach of stream investigated, but there remains a question concerning the actual increased contribution caused by the mine

spoils. It is observed from figure 8 and Table 2 that the specific conductance at station C2 did not change greatly from April to June; a time period, over which, the discharge at C2 increased several fold. This observation indicates that the water produced on the upper reaches of the watershed does not pick up an appreciable salt load from the undisturbed soils found there. The soils in the portion of the watershed immediately above the study area are derived from the Iles member of the Mesa Verde group (Bass et al.,[3] 1955), however, and the fact that no appreciable salt loading was observed at C2 may not be indicative of the quantity of salts that are derived from the undisturbed portion of the Williams Fork formation in the study area. Therefore, the specific conductance of surface and subsurface water entering the stream from the west side (not mined) was measured at eight locations along the reach between station C2 and C8. The specific conductance of the groundwater samples from the west side averaged 504 μ mohs/cm, with the highest observed conductivity being 806 μ mohs/cm. The conductivities of two groundwater samples collected upstream of both the agricultural and mined lands were 560 and 714 μ mohs/cm. These numbers are to be compared with the conductivity of groundwater on the east bank, directly below the spoils, which averaged 4105 μ mohs/cm. The specific conductance of surface runoff from the agricultural land averaged 267 μ mohs/cm.

There exists a general correspondence between the chemical characteristics of the spoils and overburden at the Edna Mine and the chemical characteristics of the runoff and groundwater. The average results from the saturated paste analysis of 14 samples of spoils, 20 samples of drill cuttings, and one composite sample of native soil are given in Table 3. Also included in Table 3 are the corresponding average results from samples of runoff and groundwater. It is noted that the ions that are dominant in the saturated paste extract are dominant in the water samples. One significant anomaly exists, however. The calcium concentration in the water samples is much larger than would be expected from the saturated paste results. This observation will be discussed in conjunction with the leaching experiments, but it remains largely unexplained.

Table 3. AVERAGE CHEMICAL CHARACTERISTICS OF SPOIL, RUNOFF AND GROUNDWATER.

Sample	pH	Specific cond.	Ca ppm	Mg ppm	Na ppm	K ppm	Cℓ ppm	SO_4 ppm
Edna spoils	8.0	3110	39	221	41	28	15	650
Edna drill cuttings	8.1	2970	38	162	83	39	31	544
Edna native soil	8.1	340	3	9	13	11	20	30
Station C3 (runoff & percol.)	7.6	2330	400	140	21	5	4	800
Station C5 (runoff & percol.)	7.7	3025	363	225	80	18	4	800
Station C7 (groundwater)	7.5	4105	312	168	541	14	8	800

Table 4. SEDIMENT CONCENTRATIONS AT STATIONS C2 AND C8.

Month	Suspended solids concen., mg/ℓ		
	Station C8	Station C2	Net
Oct	3.9	2.4	1.5
Nov	1.4	1.4	0
Dec	∿0	∿0	0
Jan	∿0	2.2	-2.2
Feb	∿0	∿0	∿0
Mar	3.0	∿0	3.0
Apr	6.2	∿0	6.2

The correspondence observed between the results of the spoil analyses and the water analyses does not extrapolate to the chemical characteristics of the soil. The levels of calcium, magnesium and sulfate in the spoil are less than one-tenth of the levels in the spoils, drill cuttings, or water samples, and are of insufficient magnitude to produce the levels of water quality degradation observed in the stream.

There are other indications that the spoils are the major cause of the water quality changes observed. During October, a salt deposit was observed along a 30 m reach of Trout Creek between stations C6 and C8. The salt was the result of evaporation of groundwater on the seepage face formed by the intersection of the water table with the stream bank. A small network of observation wells was installed in the alluvium to help determine the source of the groundwater. The measured water-table elevations are the basis for the map of figure 9 which indicates the direction of flow is from the mine, into the stream. Other groundwater seeps near the toe of the spoil banks were noted from place to place.

Sediment Pollution

The concentrations of suspended solids at the upper and lower sampling stations on Trout Creek are shown in Table 4. Data for the high runoff months of May and June are not available at the time of this writing. Since May and June are the months when the sediment concentrations are expected to be highest, no conclusions can be drawn concerning sediment loads.

Contaminant Loading

The magnitude of salt loads added to Trout Creek between stations C2 and C8 were computed by combining the discharge and concentration data into discharge rates for total dissolved solids. Because of the lack of discharge measurements at station C8 after December, it was assumed that the discharge at C8 was equal to that at C2. This assumption is probably

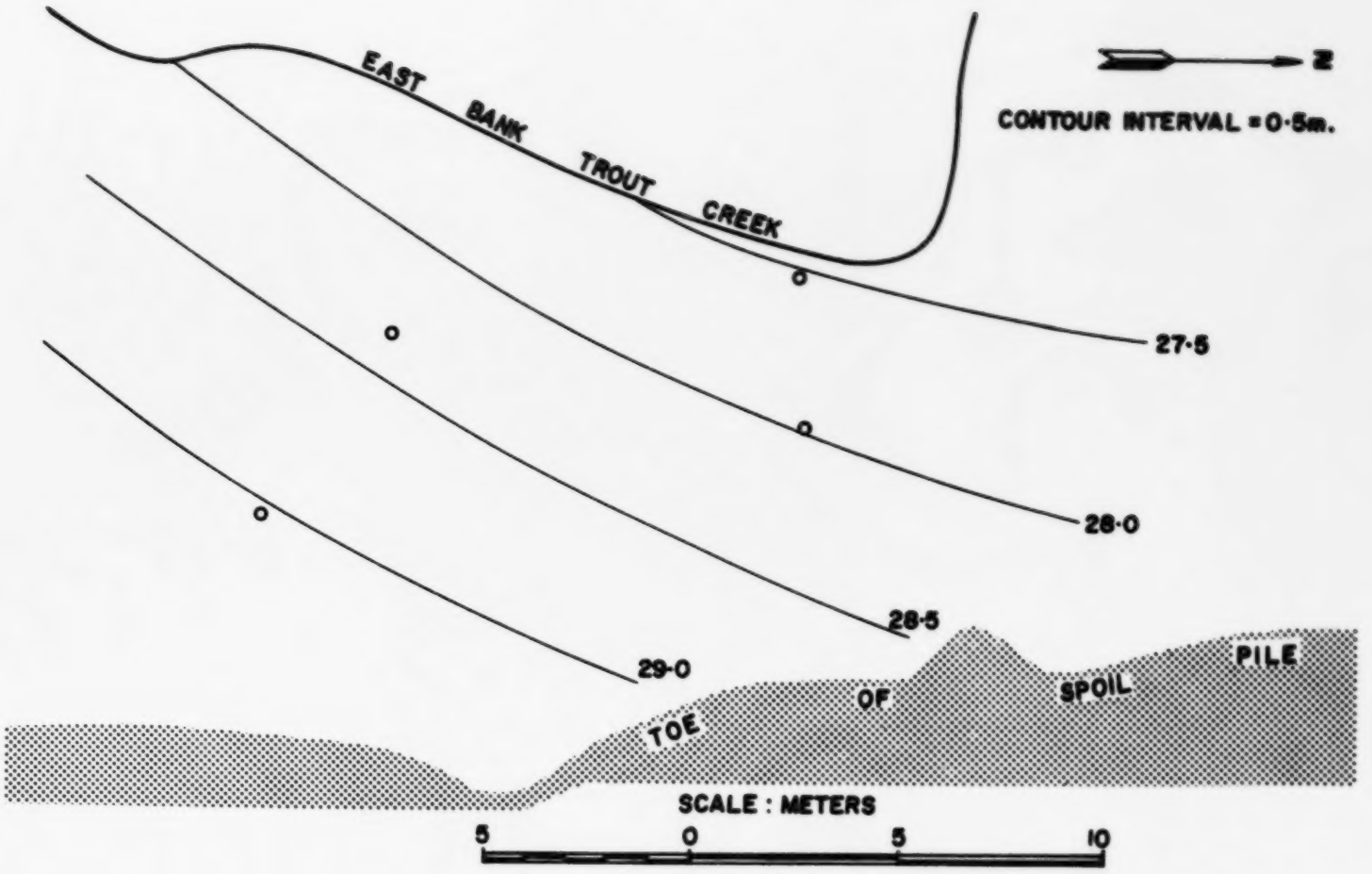


Figure 9. Water table map near station C8.

Table 5. DISCHARGE OF TOTAL DISSOLVED SOLIDS AT STATIONS C2, C3 & C8. (metric tons/month)

Month	Station C8 Q_{ds}	Station C2 Q_{ds}	Net Q_{ds}	Station C3 Q_{ds}
Oct	186	55	131	39
Nov	151	130	21	39
Dec	294	177	117	36
Jan	-	-	-	36
Feb	173	64	109	35
Mar	314	75	239	37
Apr	451	82	369	118
May	5610	1636	3974	>746
Jun	2655	1537	1118	110

quite good from October to March, but will certainly result in an underestimate at C8 during the spring runoff. Thus, the calculated stream loading is believed to be conservative.

The calculated discharges of total dissolved solids at stations C2, C3, and C8 are given by month in Table 5. Using the February results for January and adding the columns in Table 5 results in an estimated inflow of salts equal to 3820 metric tons at C2 and an estimated outflow of 10,007 metric tons at station C8. The net pick up of salt load during the nine month period is 6187 metric tons in the reach of stream between C2 and C8. The quantity of dissolved solids added at station C3 is 1196 metric tons, or nearly 20 percent of the total. It is important to note that more than 80 percent of the total load is contributed during the spring runoff in April, May, and June.

The water at station C3 is composed of both surface and groundwater runoff from the spoils immediately south of the station. It is estimated that the maximum spoil area contributing at station C3 is 142 ha (350

acres). Thus, the total salt load of 1196 metric tons measured at this station translates to 8.42 metric tons per hectare or 3.7 tons per acre for the nine month period. The corresponding quantity of surface and groundwater runoff over the same area and time period is 40 cm (16 inches) resulting in an average salt pickup rate of 0.21 metric tons per hectare per centimeter of surface and groundwater runoff (0.23 tons/acre/in).

A review of the conditions under which the above numbers were derived is important. The spoil area contributing to station C3 was mined during the period from 1947 to 1962. A substantial portion was mined by placing the spoils on undisturbed ground; thus, leaving ribbons of virgin ground beneath the spoil banks. Both the age and the method by which the spoils were handled tend to make their contribution to the salt load somewhat smaller than from fresh spoils placed in the pit. The data in Table 3 show that the station C3 water, indeed, exhibited a significantly lower specific conductance than that measured at stations C5 and C7 below the more recent spoils. Variability in spoil characteristics could also account for this observation, however. The discharge measurements at station C3 are believed to be quite accurate except for the month of May when the Parshall flume was submerged by the large flows. The maximum capacity of the flume, which was obviously less than the flow, was used for the May calculation. The pond behind the high wall at C3 dampens normal flucturations in the runoff hydrograph which helped to obtain representative flow rates.

It is believed that the figures of 6187 metric tons of salt pickup, 1196 metric tons from the area south of C3, and the per hectare pickup of 8.42 metric tons are valid estimates, and probably somewhat conservative. The 1974 spring runoff, however, was exceptionally large and definitely cannot be considered normal. Since the total salt loading is highly dependent upon the quantity of surface and subsurface runoff, it is expected that the salt production from the spoils in a normal runoff year is much less than that observed in this study. The normalized figure of 0.21 metric tons of salt pickup per hectare per centimeter of

surface and groundwater runoff is not sensitive to the magnitude of runoff, however, and can be used to estimate total salt loads for other runoff conditions. Estimates for normal runoff conditions are discussed in a subsequent section of this report.

Unfortunately, there are no other data on salt loading from strip mine spoils in the Rocky Mountain region to which the results of this study can be directly compared. There are, however, estimates of salt loading from irrigation return flows which help to place the above results in perspective. Annual salt loading from irrigation return flow has been estimated to be about 27 metric tons per hectare (12 tons/acre) in Grand Valley, Colorado (Skogerboe and Walker[9], 1972), which is roughly three times the quantity estimated herein. The irrigated areas in Colorado's Uncompahgre and Lower Gunnison River Valleys contribute an estimated salt load of 13 metric tons per hectare (6 tons/acre) annually to the streams.

IDARADO MINE SITE

An example of the analysis of in-stream water samples on the San Miguel River is presented in Table 6. The variability in water quality with time and location makes average results meaningless, and therefore, the data set which indicates the poorest water quality appears in Table 6. Again, the poorest water quality was observed at station T4 above the point of dilution by Bear Creek but downstream of four tailings ponds.

Both the hydrology and potential sources of water contaminants are much more complex at the Idarado site than at the Edna site, and it was not possible to obtain a completely clear description of the influence of the tailings piles. During the spring runoff, water enters the stream almost everywhere along the reach investigated. It was possible to determine neither the quality nor quantity of the runoff with sufficient accuracy to prepare a dissolved solids budget for the entire reach of investigated. It was possible, however, to calculate the dissolved

Table 6. APRIL, 1974, WATER QUALITY ON THE SAN MIGUEL RIVER.

Parameter	San Miguel River station T4	U. S. drinking water standards[a]
Acidity, mg $CaCO_3$/ℓ	2	-
Alkalinity, mg $CaCO_3$/ℓ	36	-
Total hardness, mg/ℓ	250	-
Specific cond., μmohs/cm	468	-
Total dissolved solids, mg/ℓ	370	500
Suspended solids, mg/ℓ	-	-
Total solids, mg/ℓ	-	-
pH	7.7	8.0
Aluminum, mg/ℓ	<0.5	-
Calcium, mg/ℓ	150	-
Chloride, mg/ℓ	3.8	250
Copper, mg/ℓ	<0.1	1.0
Dissolved iron, mg/ℓ	<0.05	0.3
Undissolved iron, mg/ℓ	-	-
Potassium, mg/ℓ	<1	-
Magnesium, mg/ℓ	5.9	125
Manganese, mg/ℓ	0.72	0.05
Sodium, mg/ℓ	6.9	-
Lead, mg/ℓ	<0.14	0.05
Sulfate, mg/ℓ	150	250
Zinc, mg/ℓ	0.14	5

[a]U. S. Public Health Service (1962).

mineral pickup between stations T4 and T8 for the months of October, November, May, and June.

The measured discharges, Q_w, at stations T4, T5, and T8 are tabulated, along with the corresponding dissolved solids concentrations, in Table 7. Also included are the calculated discharges of dissolved solids, Q_{ds}.

Table 7. DISCHARGE OF WATER AND DISSOLVED SOLIDS AT STATIONS T4, T5 AND T8.
(metric tons)

Month	Station T4			Station T5			Station T8		
	Q_w m^3/sec	Dis.solids mg/ℓ	Q_{ds} tons/mo	Q_w m^3/sec	Dis.solids mg/ℓ	Q_{ds} tons/mo	Q_w m^3/sec	Dis.solids mg/ℓ	Q_{ds} tons/mo
Oct	0.11	208	60	0.08	81	17	0.18	165	78
Nov	0.06	270	43	0.05	150	20	0.17	200	90
May	0.88	160	370	0.32	120	101	1.04	190	519
Jun	2.01	100	528	0.67	44	78	2.33	110	679

Station T5 is on Bear Creek, the only tributary to the river between stations T4 and T8. Thus, the difference between the dissolved solids discharge at T8 and the sum of the discharges at T4 and T5 is the rate of dissolved solids pickup between T4 and T8. The total dissolved solids pickup for the four months listed in Table 7 is 149 metric tons.

The source of the dissolved solids accumulated between stations T4 and T8 is tailings pond no. 6, the only presently active disposal area. The quality of percolate from tailings pond no. 6 was monitored from three groundwater sampling stations and form a subsurface drain extending under the tailings. The average water quality from the groundwater stations and from the drain are given in Table 8. Also included are the water quality parameters for the water which is used to transport the solid tailings, as well as the results from the saturated paste analysis of sample 6-5. This sample is a composite of 12 samples of tailings at different depths from four different locations on tailings pond no. 6. Incident precipitation and tailings transport water percolate into the interior of the spoil bank and build up a groundwater mound from which leachate moves toward the boundaries of the pile. This is evident from the water table map shown in figure 10, which shows the direction of groundwater flow to be toward Bear Creek on the west and the San Miguel River on the north. No piezometers were installed on the east end of tailings pond no. 6, but there is undoubtedly a component of flow to the northeast. A portion of the groundwater which moves northeast probably enters the river above station T4.

The source of salts in the tailings ponds is, evidently, quite different from that in the strip mine spoils. The water used to transport the tailings to the disposal area contains 720 mg/ℓ of dissolved solids. Combining this number with the 4.2×10^3 m^3 of transport water used in each operational day results in an estimated daily discharge of 3 metric tons of soluble salts to the disposal area. Over a sufficiently long time

Table 8. AVERAGE CHEMICAL CHARACTERISTICS OF OF WATER AND TAILINGS BETWEEN STATIONS T4 AND T8.

Parameter	Groundwater samples	Drainage samples	Transport sample[a]	Tailings
Acidity, mg $CaCO_3$/ℓ	22	3	~0	-
Alkalinity, mg $CaCO_3$/ℓ	83	52	160	-
Total hardness, mg/ℓ	576	394	310	-
pH	7.2	7.6	11	7.7
Specific cond., μmohs/cm	1406	1276	1200	2047
Dissolved solids, mg/ℓ	1000	975	720	-
Aluminum, mg/ℓ	<0.5	<0.8	1.9	-
Calcium, mg/ℓ	219	238	260	39
Chloride, mg/ℓ	4	81	>250	20
Copper, mg/ℓ	<0.1	10	20	-
Dissolved iron, mg/ℓ	<0.08	<0.05	<0.05	-
Potassium, mg/ℓ	20	34	27	58
Magnesium, mg/ℓ	7.2	1.4	0.04	15
Manganese, mg/ℓ	21	<0.5	<0.01	-
Sodium, mg/ℓ	29	70	53	64
Lead, mg/ℓ	<0.15	<0.15	0.21	-
Sulfate, mg/ℓ	389	345	180	240
Zinc, mg/ℓ	-	0.17	<0.01	-

[a]Results for one sample only.

period, it is reasonable to assume that storage of these salts in the pile approaches zero. It is expected, therefore, that the long term average contribution of dissolved solids to the receiving waters is 3 metric tons per operational day. This conclusion is derived, however, on the basis that the concentration of dissolved solids of 720 mg/ℓ, obtained from one sample of transport water, is representative. Continued monitoring of the quality of the transport water is being accomplished in order to establish an average value.

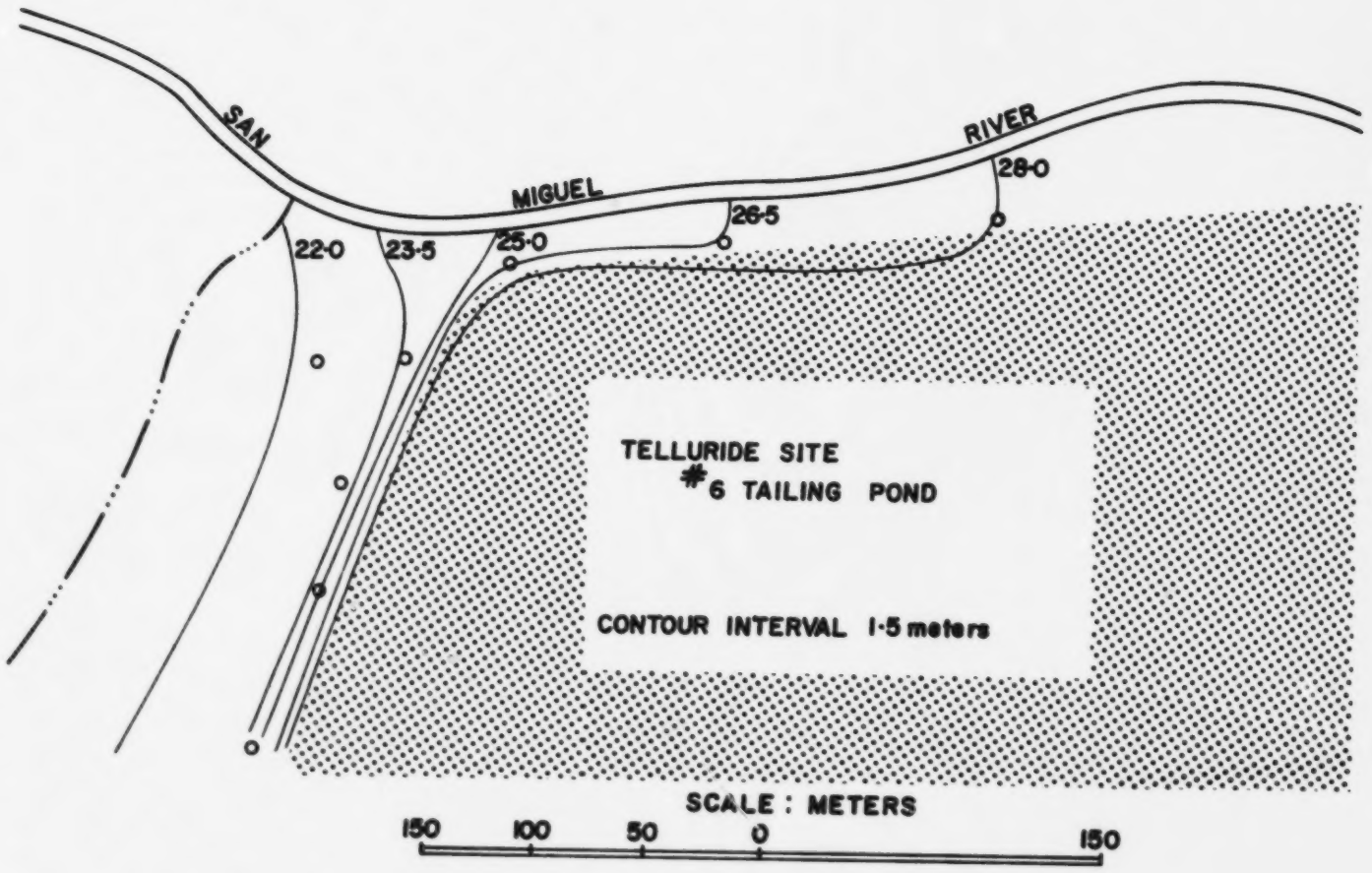


Figure 10. Water table map at Tailings Pond no. 6.

The observed salt pickup between stations T4 and T8 is not as great as might be expected from the above computation. It has already been indicated that some groundwater movement from the northeast side of tailings pond no. 6 probably enters the river above station T4 and thus accounts for part of the discrepancy. Stream depletion by flow from the stream to the groundwater aquifer is believed to contribute to the discrepancy as well. The discharge measurements on Bear Creek were made immediately above the point where Bear Creek enters the alluvium in the valley floor. This alluvium is composed of sand, coarse gravel, and cobbles. It is quite possible for significant quantities of water to flow from the stream into the alluvium on the west side of Bear Creek, while groundwater from the tailings pond flows into Bear Creek from the east side. There is also a high probability of water loss from the San Miguel River to the alluvium between the confluence with Bear Creek and station T8. These comments are strongly supported by the measured discharges at T4, T5, and T8 reported in Table 7 which show that the cumulative discharge over the four months at station T8 is only 89 percent of the sum of the cumulative discharges at T4 and T5. A loss of 11 percent to the alluvium is indicated. In addition, groundwater from the tailings pond may be moving across Bear Creek as underflow and returning as surface water downstream of station T8.

NAVAJO MINE SITE

A water quality monitoring program was not established at the Navajo site because of the intermittent nature of the runoff and limitations of time and budget. Samples of the spoil and overburden were collected, however, and subjected to saturated paste analyses. The average results of these characterizations are presented in Table 9. Also included are the corresponding chemical characteristics of a water sample from a pond located in the pit near the north end of the mine (figure 6), and of water samples collected and analyzed by Rabinowitz and Billings[2] (1973).

There exists a general correspondence among the chemical characteristics

Table 9. AVERAGE CHEMICAL CHARACTERISTICS OF WATER, SPOIL, AND OVERBURDEN, NAVAJO MINE.

Parameter	Spoils	Overburden	Pit water	Shallow wells[a]	Pictured Cliff aquifer[a]
pH	8.0	8.1	8.7	7.7	7.8
Dissolved solids,mg/ℓ	-	-	-	2609	47000
Specific cond.,μmohs/cm	3960	9390	17300	-	-
Calcium,mg/ℓ	31	40	-	153	170
Magnesium,mg/ℓ	212	229	19	31	73
Sodium,mg/ℓ	622	1800	5000	631	18700
Potassium,mg/ℓ	27	36	64	11	290
Bicarbonate,mg/ℓ	149	607	-	347	3270
Chloride,mg/ℓ	30	32	1850	53	24200
Sulfate,mg/ℓ	768	1490	-	1384	17
Copper,mg/ℓ	-	-	<0.9	<0.1	<0.1
Dissolved iron,mg/ℓ	-	-	-	0.1	<0.1
Manganese,mg/ℓ	-	-	-	0.4	<0.01
Zinc,mg/ℓ	-	-	0.02	0.2	-
Lead,mg/ℓ	-	-	<0.1	<0.1	<0.01
Aluminum,mg/ℓ	-	-	<0.5	-	-
Nitrate,mg/ℓ	-	-	20	-	-

[a]From Rabinowitz and Billings, 1973.

of the spoils, overburden, pit water and the shallow wells, even though the magnitude of the various quality parameters vary rather widely. The significant difference in the magnitude of corresponding ions in the saturated pastes prepared from the spoils and from the overburden samples can probably be explained by exposure to leaching action. The spoil samples were taken directly on the surface and ranged in age from about one year to four years, while the overburden was sampled from the high wall. Almost certainly, natural areal variability of overburden also contributes to the differences observed.

Chloride concentrations in the pit water are significantly higher than in the shallow wells. This observation is explained by the fact that the chloride ion is highly mobile in porous materials and is readily leached from the relatively fresh spoils. Most of the chloride in the materials in which the shallow wells are dug would be expected to be leached out long ago. The same reasoning applies to the difference noted in the sodium concentrations, except in this case, sodium is flushed from exchange sites on the clay particles and replaced by calcium and magnesium. The above observations and discussion indicate that surface and subsurface runoff, from spoils with chemical characteristics similar to those determined from the limited number of samples analyzed, will contain larger concentrations of soluble salts, principally sodium and chloride, than runoff from undisturbed ground. Because of the variability in spoil and overburden characteristics and the very limited areal distribution of sampling, the degree to which the above discussion applies to the entire disturbed area is unknown.

The sodium and chloride concentrations in the Pictured Cliff aquifer below the Fruitland formation are extremely high. A reasonable explanation of this observation is the gradual concentration of these ions by percolating water from the Kirtland and Fruitland formations above. Even extremely small interchanges of water between the Pictured Cliff and the overlying materials are sufficient to account for the high concentrations, given the millions of years over which the flow could take place. In any case, deep percolation that may occur through the mine spoils and eventually into the Pictured Cliff aquifer cannot significantly degrade the already unuseable water.

SECTION VII
GENERAL CHEMICAL AND GEOLOGICAL CONSIDERATIONS

The problem of salinization of land and water resources in the arid and semi-arid regions of the world is one of long standing; dating back to the early civilizations in the Tigris and Euphrates Valleys. Salts in soils generally originate from the weathering process. In humid climates, natural precipitation is typically sufficient to leach out the soluble salts as rapidly as they are formed. This is not true in arid regions, however. Much of the soil in arid regions has been derived from shales, sandstones, glacial and wind-borne deposits, and unconsolidated alluvium of various geologic ages. Shales commonly contain substantial amounts of soluble salts. Kelley[10] (1951) reports that the soluble salts found in soils of dry climates can be traced to such secondary formations. Regardless of the original source of the salts in the parent materials, the salts usually remain inadequately leached in arid and semi-arid climates, except possibly in the top few centimeters of the soil profile. Disruption of saline shales and sandstones exposes fresh surfaces for leaching, and for a period of time, will influence the quality of surface and subsurface runoff. There is evidence that the spoils produced by strip mining throughout Rocky Mountain and Northern Great Plains regions will contain significant quantities of soluble salts. Hodder and Sindelar[11] (1972) report saline spoils in the Decker, Montana area. Sandoval et al.[12] (1973) present saturation extract data on 12 spoil samples in the Northern Great Plains region which are quite similar to that reported herein. All of these spoils, including those studied in this investigation, are produced from Upper Cretaceous and Early Tertiary overburden materials.

An examination of the water quality data (appendix A) and the saturated soil paste analyses (appendix C) for the Edna Mine indicates that magnesium and calcium are the primary cations while sulfate and bicarbonate are the principle anions. The sodium, potassium, chloride and nitrate

are of secondary prominence. Correlation analyses of the various anion/cation combinations possible indicates (figure 11) that the sulfate concentrations in both the soil/overburden samples and the water are correlated with the total calcium plus magnesium concentrations (in millimole units). Neither sodium nor potassium correlate with the sulfate. The total millimole amounts of these last two cations do correlate well, however, with the total millimoles of chloride plus nitrate in the soil analysis results. The soil bicarbonate levels do not correlate with any cation/anion combination. These observations imply that gypsum ($CaSO_4 \cdot 2H_2O$) and epsomite ($MgSo_4 \cdot 7H_2O$) account for the major portion of the sulfate present in the ground water and the stream input. Alkali metal contributions appear to be primarily due to the presence of lesser amounts of sodium and potassium chlorides and nitrates (with the nitrates being more prominent).

This inference is supported by X-ray powder diffraction analysis of salt deposits accumulated along the banks of Trout Creek. The deposit contained primarily calcium and magnesium sulfate with lesser amounts of the sodium and potassium analogs. The analyses distinctly show the predominance of sulfate equilibria in the ground water. The most obvious implication is that the primary sulfate input is due to dissolution of gypsum and epsomite present in the overburden. The presence of these minerals in formations of this type is quite common (Kelley,[10] 1951; Boyko,[13] 1966; Richards,[14] 1954). An alternate source of sulfate may be the action of sulfur-oxidizing (chemotrophic) bacteria within the soil matrix to form sulfate. The characterization of such production has been discussed by Galbraith et al. (1972). While this type of mechanism may be operative, the present authors believe that it is unlikely to be of prominent significance for the systems studied.

Other equilibrium considerations of importance may involve reactions between soluble and exchangeable cations. Cation exchange phenomena often occur in soils. The reaction between calcium saturated soil and a sodium chloride solution, for example, can be written:

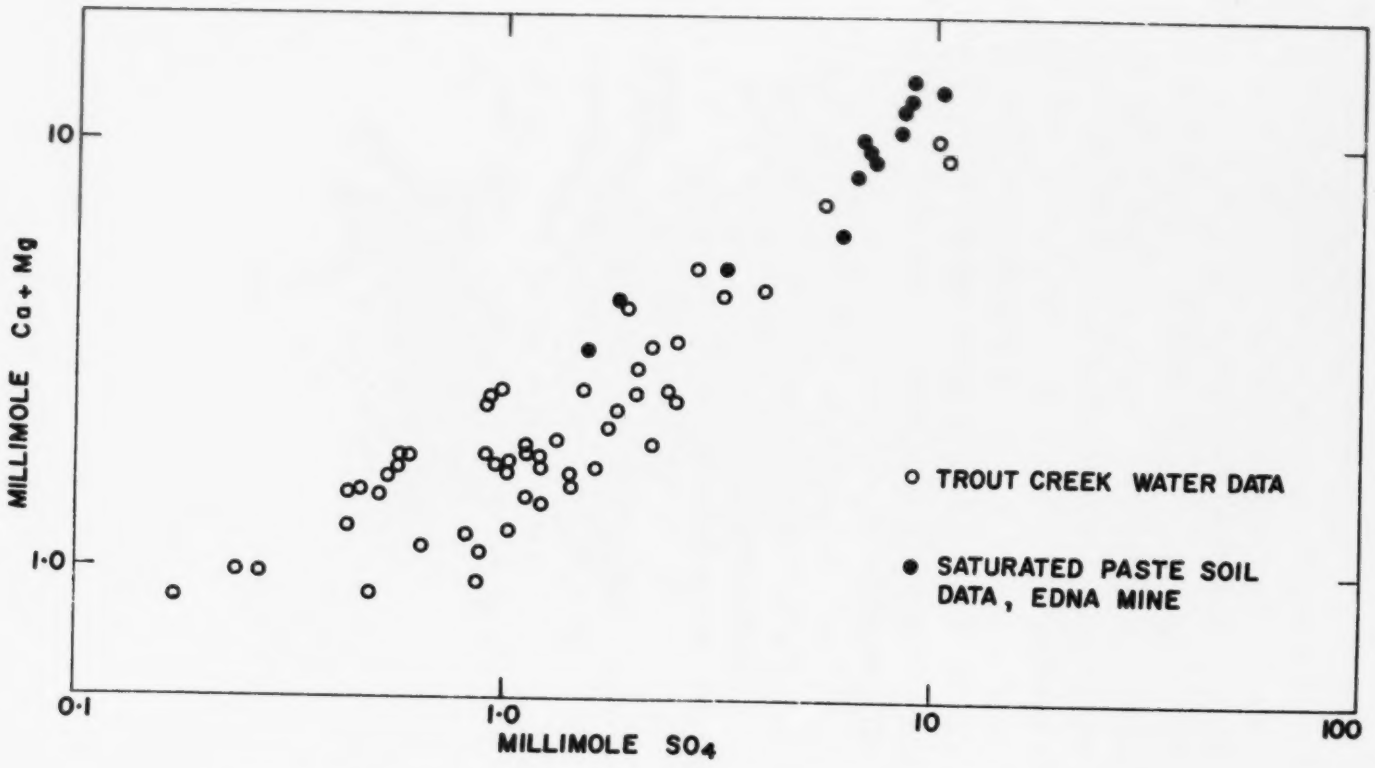


Figure 11. Correlation of calcium and magnesium with sulfate.

$$CaX_2 + 2NaCl = 2NaX + CaCl_2$$

where X denotes the soil exchange site (e.g. clay). As long as soluble calcium is available, the reaction will not go to completion, but an equilibrium will be established between calcium ion and complexed calcium. Such ion exchange sites have an almost universally higher affinity for calcium ion relative to that for sodium ion, i.e., calcium ion will readily replace sodium or potassium on the ion exchange sites. The same applies to magnesium. As a result, the addition of gypsum ($CaSO_4$) to saline soils has been widely recommended as a means of forcing alkali metals from the exchange sites so they can be flushed from the soil via adequate subsoil drainage (Richards, 1954). The presence of gypsum and epsomite in the present systems indicates that this phenomenon could be operative and could serve as a source of sodium/potassium input to the ground water and thence the stream. The possible extent of such mechanisms depends, of course, on the total cation concentration of the ground water. The USDA Soil Salinity Lab (Richards, 1954) has pointed out that the sodium adsorption ratio (SAR) may be employed for discussing the equilibrium relation between soluble and exchangeable cations. The SAR may be computed from:

$$SAR = \frac{(Na^+)}{\left[\frac{(Ca^{++})+(Mg^{++})}{2}\right]^{\frac{1}{2}}}$$

where ( ) denotes the milliquivalent concentrations of the respective ions. Another important quantity is the exchangeable-sodium-percentage (ESP), which indicates the number of total exchange sites in the soil which contain sodium. The ESP thus serves as a measure of the amount of sodium which could be "flushed" from the exchange sites under the proper conditions, for example, through the addition of gypsum or epsomite.

The SAR values calculated from the saturated paste results for the Edna spoils produced an average value of 0.5. Such low SAR values are indicative of ESP values of less than 1-2 percent. In essence, there is very

little sodium or potassium available in these samples which could be removed from exchange sites. This implies that; (1) there are very few cation exchange sites available in the materials; or, (2) the exchange sites have already been flushed free of sodium or potassium. The relatively high clay contents of the samples in question indicates that the latter possibility is most likely. The general prominence of calcium and magnesium in the soil and ground water samples is also supportive of this possibility.

The data presented above strongly imply that gypsum and epsomite are primary sources of calcium, magnesium, and sulfate. Because dolomite ($Ca\ Mg\ (CO_3)_2$) and calcite ($CaCO_3$) constitute a large fraction of the total carbonate rocks, it would not be unreasonable to expect that these two minerals might serve as contributors to the calcium, magnesium, and total carbonate concentrations. Hsu[16] (1963) has pointed out that subsurface waters tend to have Ca^{+2}/Mg^{+2} concentration ratios indicative of the type of carbonate with which they are in equilibrium. Strum and Morgan[17] have developed stability relations for Ca^{+2}-Mg^{+2}, CO_2-H_2O systems which may be used to <u>crudely</u> infer the identity of the carbonate mineral/water system. The water quality data for Trout Creek generally shows Ca/Mg ratios of 1.5 to 2.0. Such ratios imply the predominance of calcite dissolution if carbonates are primary sources of the calcium and magnesium. The fact that calcium carbonates are generally 3 to 4 orders of magnitude less soluble than the sulfate implies that carbonate dissolution plays a minimal role. The water quality measurements and the soil analyses, however, both indicate the existence of carbonate equilibria. A simple model of aqueous carbonate solutions predicts that the prominent carbonate species in water with a pH of about 7.7 will be the bicarbonate ion. This explains the fact that no carbonate ion was detected in the saturated paste analyses.

The results of the saturated paste analysis (appendix D) for the Navajo spoils and overburden are significantly different than for the Edna spoils. In particular, the sodium concentrations exceed the combined

concentrations of calcium and magnesium. Correlation analysis of these results indicates that the sulfate concentration correlates better with the sodium concentration than with the total calcium plus magnesium concentration. This implies that sodium sulfate is the major source of sulfate in the Navajo spoils, but does not rule out contributions from calcium and magnesium sulfates. The clay minerals in the Navajo spoils can be characterized as sodium saturated, as indicated by the sodium adsorption ratios and the exchangeable sodium percentages listed in Table 10. Such materials are notorious for their low water-intake capacity caused by clay particle expansion.

Table 10. SODIUM ADSORPTION RATIOS AND EXCHANGEABLE SODIUM PERCENTAGES FOR NAVAJO SAMPLES.

Sample	SAR	ESP
R-1	12.1	16
R-2	4.7	5.5
R-3	15.9	22
R-4	14.4	20
R-5	22.7	37
R-6	15.5	22
FB1	36.3	50
FB2	38.9	57
FB3	28.1	40

The mineral composition of the water in the San Miguel River and its tributaries would be expected to be quite different from that at the Edna or Navajo sites because the origins of the minerals are igneous, intrusive rocks. The overall chemical composition of the water samples is extremely difficult to explain in detail and will require a great deal more research before it is adequately understood. It is possible, however, to take a quantitative approach to the sulfide equilibria that

are certainly involved. Using the zinc sulfide mineral, sphalerite, as a specific example, the dissolution reactions may be represented by

$$ZnS_{(s)} \rightleftarrows Zn^{+2} + S^{-2}$$

The solubility product constant for ZnS is $3x10^{-22}$ suggesting that its solubility in water and therefore its contribution to the degradation of water quality would be very low. Actually, the solubilities of metal sulfides are controlled by acid-base (hydrolysis) reactions involving the sulfide ion and by reactions involving the conversion of the metal sulfides to more soluble salts. The hydrolysis of the sulfide ion produced from the dissolution of metal sulfides is a two-step process described by:

$$S^{-2} + H_3O^+ \rightleftarrows HS^- + H_2O \qquad (a)$$

$$HS^- + H_3O^+ \rightleftarrows H_2S + H_2O \qquad (b)$$

$$S^{-2} + 2H_3O^+ \rightleftarrows H_2S + 2H_2O \qquad (c)\ \text{(overall reaction)}$$

The equilibirum constants of these reactions are given by:

$$K_a = \frac{(H_3O^+)(S^=)}{(HS^-)} = 1.2x10^{-13}$$

$$K_b = \frac{HS^-)(H_3O^+)}{(H_2S)} = 1x10^{-7}$$

and

$$K_c = \frac{(S^{-2})(H_3O^+)}{(H_2S)} = \frac{K_aK_b}{(H_3O^+)} = \frac{1.2x10^{-20}}{(H_3O^+)}$$

Therefore:

$$\frac{(S^{-2})}{(H_2S)} = \frac{1.2x10^{-20}}{(H_3O^+)^2}$$

These equations show that the sulfide released during the dissolution of metal sulfides is essentially all converted to HS^- at pH values ranging from approximately 8 to 11; if the pH is below approximately 7, the sulfide is converted largely to H_2S. The result is the effective removal of sulfide ion itself from the system, thereby allowing dissolution

of more metal sulfide. Using the equilibria constants outlined above, the calculated solubility of ZnS at pH of 6 is approximately 2 ppm. This value is below that often observed for the water quality measurements. Some of this discrepancy is due to the formation of soluble zinc hydroxide and $Zn(HS)_n$ complexes which effectively increase the solubility of the metal sulfide. The presence of sulfate in the water may offer a more logical explanation for the discrepancy. Sulfate ion reacts quite readily with most metal sulfides to form the corresponding sulfates. These sulfates are universally more soluble than the sulfides. Galbraith et al.[15] (1972) have considered this possibility as a likely explanation.

SECTION VIII

PROJECTED WATER QUALITY DEGRADATION FROM STRIP MINE SPOILS

The discussion thus far has centered around the nature and magnitude of water quality degradation observed at the study sites over a nine month period. The data presented are not indicative of the average situation, however; nor do they provide direct information on the total quantities of salt that will eventually be produced nor the time period over which the salt pickup will remain above ambient levels. The most efficient and reliable method of obtaining answers to the above questions is through the use of a well verified mathematical model. Such a model is not available at this time, and therefore, the estimates presented in this section are derived by methods requiring more assumptions, judgment, and speculation than is desirable. The authors believe, however, that it is important to establish "order of magnitude" values for average salt pickup rates and total salt pickup so that the problem of salt production from strip mine spoils can be more accurately judged in relation to national priorities and future research needs. The authors regard the numerical quantities reported in this section as indicators of magnitude and attach a limited significance to the actual numbers.

TOTAL LEACHABLE SALTS

Estimates of the total quantities of soluble salts were derived from the leaching experiments described earlier in this report. The results of the leaching experiments are summarized in figures 12 and 13. The relationshops shown in these figures were prepared from the data tabulated in appendix F. The specific conductance of each increment of leachate has been normalized by dividing by the conductance of the saturated paste extract corresponding to each column. These values were then plotted as a function of the cumulative leachate volume expressed as a ratio to the bulk volume of sample. This method of handling the data caused the results from the three Navajo columns to

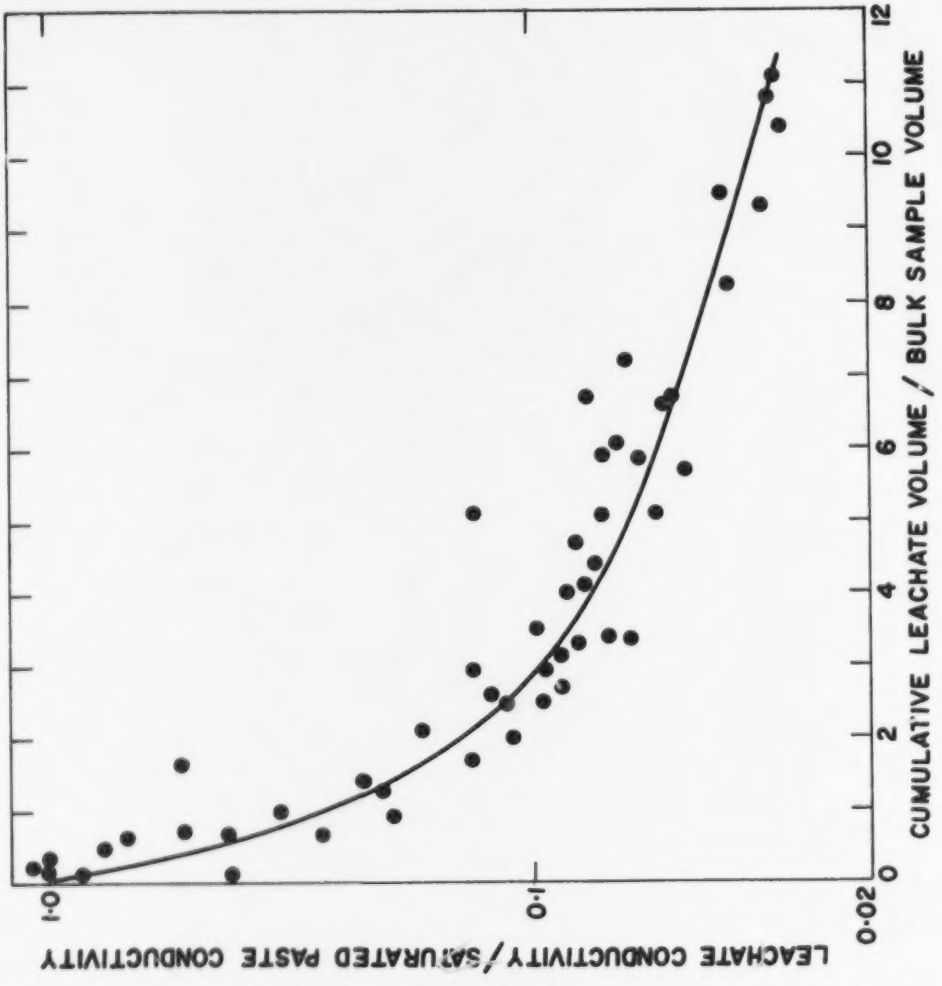


Figure 12. Normalized leaching data from three samples of overburden - Navajo Mine.

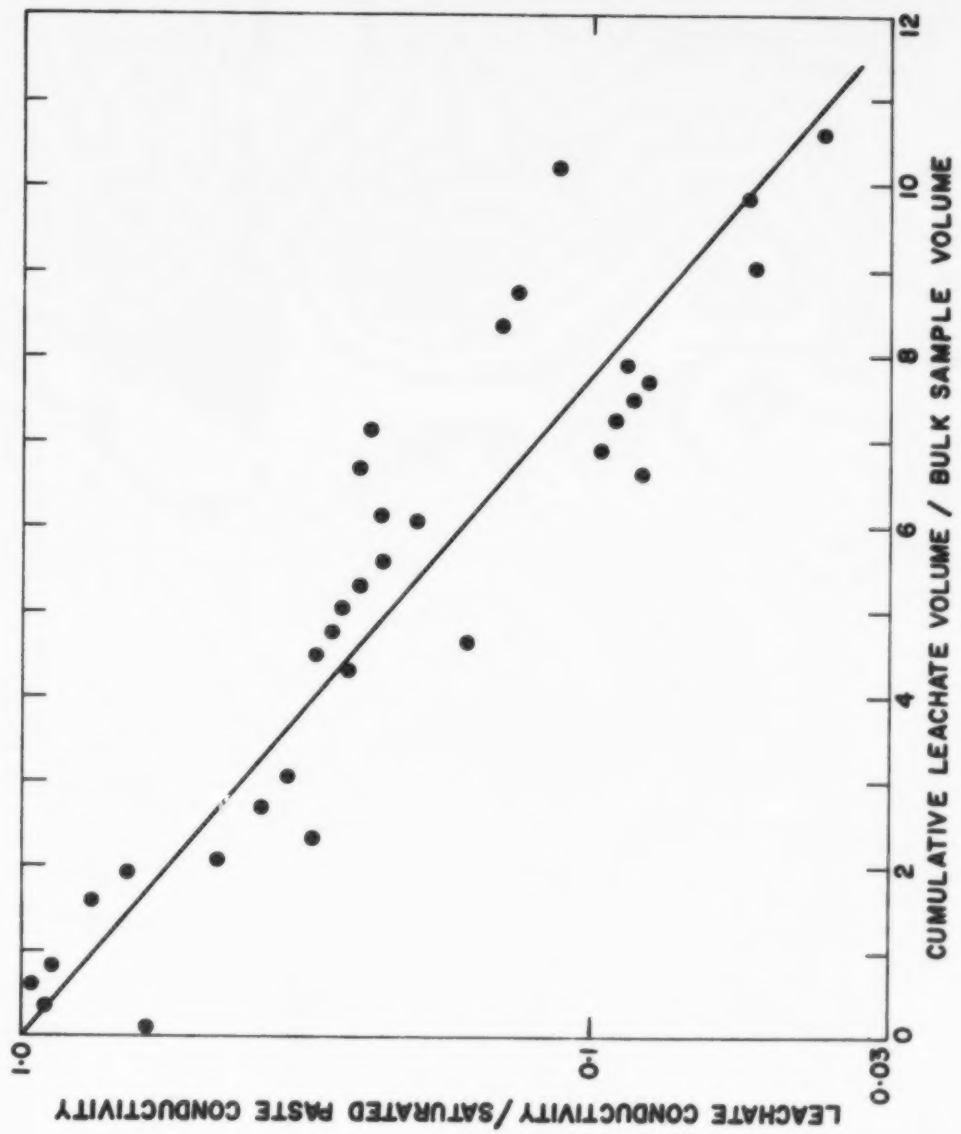


Figure 13. Normalized leaching data from six samples of spoils and overburden - Edna Mine.

define a single relationship fairly well as shown in figure 12. The same procedure was used to obtain the curve shown in figure 13 for the six Edna columns. Before normalizing the data in the above manner, each test defined a distinct and individual relationship.

Assuming that the soluble salt concentration is proportional to the specific conductance, the area under the curves in figures 12 and 13 in any increment of leachate volume is proportional to the quantity of salts removed in that increment. The total quantity of soluble salts per unit volume of spoil can be determined by this procedure, only if an effectively infinite volume of leachate is collected. Therefore, it is arbitrarily assumed that removal of salt is negligible after the conductivity of the leachate has decreased to 5 percent of the saturated paste conductivity. It is noted from figures 12 and 13 that this criterion requires a total throughput of water equal to 10.1 times the volume of the Navajo samples and 6.8 times the volume of the Edna samples. The average saturated paste conductivities for the Edna samples and for the Navajo spoils are 3110 and 9390 micro-mohs/cm, respectively. Using the Handbook 60[14] (1954) correlation between specific conductance and total dissolved solids, the corresponding dissolved salts concentrations are 2200 ppm and 7300 ppm. Using these concentrations and integrating the functions in figures 12 and 13 to the cumulative leachate volumes corresponding to a 95 percent reduction in specific conductance, results in estimated removable salt contents of 2.4 kg/m^3 for the Edna spoils and 23 kg/m^3 for the Navajo overburden.

The numbers computed above imply that 2.4 kg of salts must be removed from each cubic meter of Edna spoil and 23 kg from each cubic meter of Navajo material before the concentration of salts in the throughput water is reduced to a negligible level. Strictly speaking, these quantities apply precisely only to the samples subjected to leaching. Very significant variations in salt content with location can be expected, especially at the Navajo Mine. Literally hundreds of such tests might be required to establish a statistically significant

distribution of salt contents. This procedure was beyond the scope of this work. Weathering and microbial activity over long time periods are very likely to cause the total quantity of soluble salts to be even higher than calculated from the leaching experiments. The weathering rate of some shales and siltstones exposed on the spoil surface was observed to be very rapid. Apparently competent shale fragments were observed to crumble and disseminate in a matter of a few weeks upon exposure at the surface. Traces of salt deposits formed by evaporation from the shale surfaces were evident upon close examination. In addition, no statistically significant increase of soluble-salt content with depth of sampling was observed in the Edna spoils. These observations indicate that continual exposure of fresh surfaces by weathering processes will tend to make the total quantity of salts eventually removed to be higher than that observed in the leaching experiments.

AVERAGE ANNUAL SALT PICKUP

The salt pickup rate and, therefore, the time required for salt removal, depend heavily upon the quantity of surface and subsurface runoff from the spoils. The average annual surface and subsurface runoff are difficult to estimate, however. Approximately one-half of the annual precipitation of 51 cm (20 in) that falls at the Edna site is in the form of snow. Thus, the quantity of water that becomes available for infiltration, runoff, or evaporation during the spring months of April and May is much larger than the quantity of precipitation during these months and the infiltration capacity is exceeded. Surface runoff from the spoils is quite small at all other times of the year, however.

Based on an estimated mean annual discharge of 2.84×10^7 m^3 (2.3×10^4 acre-feet) for Trout Creek at the downstream limit of the Edna Mine and a watershed area of 1.1×10^4 ha(43 square miles), the average annual surface and subsurface runoff is 26 cm (10 in). The large fraction of the watershed is at higher elevations and receives more precipitation than the Edna study area, however. This fact indicates that the surface and

subsurface runoff from the spoils would probably be less than 26 cm. On the other hand, most of the watershed is very well vegetated which would tend to increase evapotranspiration relative to the less vegetated spoils. In the absence of a better estimate, 26 cm of surface and subsurface runoff is assumed to apply to the Edna spoil area. The normalized salt pickup rate of 0.21 metric tons per hectare per centimeter of runoff, derived in a previous section of this report, and the above figure of 26 cm results in an estimated average annual salt pickup rate of 5.5 metric tons per hectare per year (2.4 tons/acre/year). Surface and subsurface runoff and precipitation measurements at the Edna site will continue through June, 1976, in an attempt to refine and establish a reliable average annual salt pickup.

It is interesting and important to calculate the normalized annual salt pickup rate from the results of the saturated paste analyses. The average saturated paste conductivity for the Edna spoils is 3110 micro-mohs/cm which corresponds to a dissolved solids concentration of 2200 ppm (USDA,[14] 1954). Assuming that the dissolved solids concentration in surface and subsurface runoff is also 2200 ppm, the calculated normalized salt pickup rate is 0.22 metric tons per hectare per centimeter of surface and subsurface runoff, which agrees quite closely with the measured value of 0.21. The agreement is important because it implies that total salt pickup can be estimated from the relatively simple saturated spoil analysis and a knowledge of the hydrology; thus, providing a method of judging one of the impacts of strip mining before ground is broken.

A normalized salt pickup rate for the Navajo spoils was not measured, and therefore, is calculated from the specific conductance of the overburden sample analyses. The only justification for this approach is the observed agreement between the measured and calculated values of normalized salt pickup rate at the Edna Mine. The average specific conductance is 9390 micro-mohs/cm which corresponds to a concentration of 7300 ppm; a value considerably lower than that observed in a drainage pond in the pit (see Table 9). The normalized salt pickup rate is 0.73

metric tons per hectare per centimeter of surface and subsurface runoff (0.79 tons/acre/in).

The average annual surface and subsurface runoff from the Navajo spoils is difficult to determine with accuracy. The spoils are regraded so as to preclude surface runoff in significant quantities beyond the boundaries of the disturbed area. Many small closed basins are formed, in which, all incident precipitation evaporates and percolates into the subsurface. The problem is to estimate the quantity which eventually results in deep percolation. Actual measurement of the quantity of deep percolation from a statistically significant number of the small basins over a time period sufficient to establish an average value would constitute an expensive and time consuming project. Therefore, an indirect estimate was made. Although the accuracy of the following estimate of subsurface runoff (deep percolation) is certainly open to question, the resulting salt pickup rate is so low that a concerted effort to refine it by direct measurement seems unwarranted. This is especially true since the possibility of the estimated deep percolation being grossly lower than the actual value is quite remote, and since the pre-existing groundwater is highly mineralized.

An estimate of the quantity of subsurface runoff was based on laboratory and field measurements of evaporation from bare soil by Gardner[19,20] (1973,1974). Gardner[19] found that 69 percent of the total quantity of water applied to three columns of a loamy sandy soil, in a variety of time and quantity distributions, was evaporated under conditions in which the ability of the soil to transmit water to the evaporating surface was limiting. In field experiments with a fallow silty loam soil over a four year period, Gardner's[20] data shows that an average of 70 percent of the incident precipitation was evaporated. The low was 65 percent and the high was 74 percent. The quantities of precipitation were not reported in the above referenced papers, but were obtained by personal communication. The measurements were conducted in eastern Colorado during the summer growing season when the potential evaporation

was not limiting.

The spoil materials at the Navajo Mine weather to produce soils with a variety of textural classifications. Many of them are heavier soils than a silty loam, however, and the percent of infiltrated water that eventually evaporates is likely to be larger in the heavier soil. Thus, the percent of infiltrated water which eventually evaporates from the Navajo spoil was arbitrarily taken as 90 percent. This results in an estimated annual deep percolation of 1.7 cm which was rounded to a value of 2 cm. The annual salt pickup rate is estimated to be 1.4 metric tons per hectare (0.6 tons/acre). The net salt pickup caused by mining is even lower because the dissolved solids concentration in surface and subsurface runoff from undisturbed ground may be 2500 ppm or more (Rabinowitz and Billings,[2] 1973).

SECTION IX

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APPENDIX A

WATER QUALITY DATA - EDNA MINE SITE

Table A-1. DESCRIPTION OF WATER SAMPLE LOCATIONS AT EDNA MINE SITE.

Sample designation	Description[a]
C1	Surface water sample from Trout Creek above all active mining on the water shed.
C2	Surface water sample from Trout Creek immediately above the Edna Mine.
C3	Water sample from surface and subsurface drainage tributary to Trout Creek near the southwest limit of spoil area.
C4	Surface water sample from Trout Creek below the south mined area and immediately above the active north mined area.
C5	Water sample from surface and subsurface drainage tributary to Trout Creek between the south and north mined area.
C6	Surface water sample from Trout Creek near the downstream limit of mining and immediately above irrigation diversion.
C7	Groundwater sample from seepage face immediately below the north mined area.
C8	Surface sample from Trout Creek at the downstream limit of mining activity.
CP1	Groundwater sample from observation well near station C4.
May Runoff	Direct surface runoff from a spoil bank in the south mined area.

[a]See figure 4 in text.

Table A-2. WATER ANALYSIS DATA FOR OCTOBER 1973.

Sample	Temp °C	Acidity, mg $CaCO_3$/ℓ	Alkalinity, mg $CaCO_3$/ℓ	Hardness total, mg/ℓ	pH	Specific conductance, μmhos	Suspended solids, mg/ℓ	Total dissolved solids, mg/ℓ	Total solids, mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis. mg/ℓ	Fe undis. mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
C1	5.0		85	96	7.2	61	50	19	69	<0.1	24	<1	<0.1	<0.05	0.29	0.29	<1	7.6	<0.05	3.0	<0.045	<1	<0.005
C2	5.5		96	96	7.1	65	2.4	57	59	<0.1	23	<1	<0.1	0.13	0.16	0.29	<1	7.6	<0.05	3.0	<0.045	48	0.040
C3	10.0		110	1980	7.4	2450	1.3	2482	2483	<0.1	320	6	<0.1	<0.05	0.21	0.21	3.2	50	0.05	21	<0.045	1000	0.013
C4	11.7		100	120	7.7	273	2.4	132	134	<0.1	39	<1	<0.1	<0.05	-	-	1.6	13	-	5.0	<0.045	42	<0.005
C5	13.5		180	2590	7.7	3480	6.8	3467	3474	<0.1	290	5	<0.1	<0.05	0.10	0.10	16	50	0.04	110	<0.045	1095	<0.005
C6	12.5		110	160	7.8	270	2.6	82	85	<0.1	38	1	<0.1	<0.05	0.21	0.21	<1	14	<0.05	5.6	<0.045	<1	0.021
C7	6.5		>200	1430	7.2	3680	34	3414	3448	<0.1	210	8	<0.1	<0.05	-	-	12	47	<0.05	320	<0.045	540	0.013
C8	7.2		110	200	7.5	277	3.9	192	196	<0.1	38	1	<0.1	<0.05	0.28	0.28	2.6	14	<0.05	7.8	<0.045	140	0.015
CP1																							

Table A-3. WATER ANALYSIS DATA FOR NOVEMBER 1973.

Sample	Temp °C	Acidity, mg $CaCO_3$/ℓ	Alkalinity, mg $CaCO_3$/ℓ	Hardness total, mg/ℓ	pH	Specific conductance, μmhos	Suspended solids, mg/ℓ	Total dissolved solids, mg/ℓ	Total solids, mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis. mg/ℓ	Fe undis. mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
C1	2.5		91	98	7.5	161	-	160	-	<0.1	31	<1	<0.1	0.06	-	-	<1	8.8	<0.05	3.2	<0.1	24	0.015
C2	3.0		91	95	7.6	164	1.4	160	160	<0.1	31	<1	<0.1	<0.05	0.12	0.12	1.0	8.8	<0.05	3.2	<0.1	27	0.015
C3	4.5		120	>>1000	8.1	2580	9.2	2500	2510	<0.1	360	4.8	<0.1	<0.05	-	-	5.7	46	0.06	25	<0.1	>400	0.072
C4	3.5		200	140	7.7	222	-	210	-	<0.1	47	1.2	<0.1	<0.05	-	-	1.3	13	0.05	4.9	<0.1	55	0.01
C5	5.4		160	>>1000	7.7	3080	-	3180	-	<0.1	300	5.1	<0.1	<0.05	-	-	17	41	<0.05	92	<0.1	>400	0.01
C6	5.5		100	140	7.1	270	.73	220	220	<0.1	48	1.0	<0.1	<0.05	0.14	0.14	<1	13	<0.05	5.4	<0.1	52	0.005
C7	6.7		230	>1000	6.0	3850	27	3400	3430	<0.1	250	7.8	<0.1	<0.05	0.24	0.24	1.9	48	<0.05	460	<0.1	>400	0.015
C8	5.0		100	150	7.7	278	1.4	185	190	<0.1	51	2.2	<0.1	<0.05	0.26	0.26	1.6	14	<0.05	8.2	<0.1	56	0.01
CP1	-		300	290	7.4	3680	-	2200	-	<0.1	150	8.2	<0.1	-	-	-	1.3	45	1.2	22	<0.1	>400	13

Table A-4. WATER ANALYSIS DATA FOR DECEMBER 1973.

Sample	Temp °C	Acidity, mg $CaCO_3$/ℓ	Alkalinity, mg $CaCO_3$/ℓ	Hardness total, mg/ℓ	pH	Specific conductance, μmhos	Suspended solids, mg/ℓ	Total dissolved solids, mg/ℓ	Total solids, mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis. mg/ℓ	Fe undis. mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
C1	0.0	0	110	100	7.7	183	0	100	100	<0.5	36	<1	<0.01	<0.05	0.033	<0.05	1.0	8.9	0.010	3.1	<0.16	42	0.024
C2	0.0	6	110	100	7.6	187	0	120	120	<0.5	35	<1	<0.01	<0.05	0.070	0.07	1.0	8.6	0.015	3.0	<0.16	5	0.014
C3	1.0	6	110	1800	7.4	2510	0	2300	2300	0.6	370	5.0	<0.01	<0.05	0.12	0.12	4.8	160	0.34	21	<0.16	>460	0.094
C4	1.2	0	100	160	7.4	305	0	160	160	<0.5	61	0.9	<0.01	<0.05	-	-	1.5	16	0.019	4.7	<0.16	56	<0.01
C5	1.2	0	160	2300	7.4	3160	0	3200	3200	<0.5	340	4.3	<0.01	<0.05	-	-	13	240	<0.010	92	<0.16	>800	0.035
C6	0.5	6	58	140	7.2	355	0	170	170	<0.5	53	0.9	<0.01	<0.05	0.095	0.095	1.4	14	<0.010	5.9	<0.16	50	0.008
C7	4.2	6	350	1600	7.5	4700	5.1	3400	3410	<0.5	250	8.9	<0.01	<0.05	0.055	0.055	17	150	<0.010	1099	0.20	>450	0.019
C8	0.0	6	44	150	7.2	285	0	200	200	<0.5	50	0.9	<0.01	<0.05	0.031	<0.05	2.2	14	<0.010	7.3	<0.16	59	0.014
CP1	-	15	270	1800	7.4	3610	680	2660	3440	<0.5	-	5.0	<0.01	<0.05	0.049	<0.05	7.6	210	1.3	22	<0.16	>400	39

Table A-5. WATER ANALYSIS DATA FOR JANUARY 1974.

Sample	Temp °C	Acidity, mg $CaCO_3$/ℓ	Alkalinity, mg $CaCO_3$/ℓ	Hardness total, mg/ℓ	pH	Specific conductance, μmhos	Suspended solids, mg/ℓ	Total dissolved solids, mg/ℓ	Total solids, mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis. mg/ℓ	Fe undis. mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
C1	1.0	0.0	85	95	7.7	183	0	110	110	<0.05	32	<1	<0.01	<0.05	0.10	0.10	<2	8.1	<0.01	3.0	<0.14	64	<0.01
C2	0.5	0.0	85	95	7.8	187	2.2	110	110	<0.05	34	<1	<0.01	<0.05	0.10	0.10	<2	8.4	<0.01	3.0	<0.14	82	0.008
C3	0	0.0	120	1700	7.9	2350	4.7	2300	2300	0.05	380	>100	<0.01	<0.05	0.60	0.60	4.7	150	0.38	20	<0.14	>800	0.044
C4	0	0.0	93	140	8.0	255	3.7	170	170	<0.05	46	<1	<0.01	<0.05	0.15	0.15	<2	13	0.022	4.0	<0.14	100	<0.01
C5	0.5	0.0	140	2000	7.7	2800	0	2800	2800	<0.05	330	3.0	<0.01	<0.05	0.004	<0.05	13	230	<0.01	95	<0.14	>800	0.019
C6	1.0	0.0	100	140	8.1	280	6.0	190	200	<0.05	48	<1	<0.01	<0.05	0.13	0.13	<2	14	0.026	4.6	<0.14	100	<0.01
C7	4.0	0.0	350	1500	7.9	4340	23	3700	3720	0.05	260	8.0	<0.01	<0.05	0.052	0.052	18	150	<0.01	1050	<0.14	>800	<0.01
C8	0.5	2.0	100	150	8.1	310	0	210	210	<0.05	52	<1	<0.01	<0.05	0.11	0.11	<2	14	0.024	6.0	<0.14	110	0.024
CP1																							

Table A-6. WATER ANALYSIS DATA FOR FEBRUARY 1974.

Sample	Temp °C	Acidity, mg $CaCO_3$/ℓ	Alkalinity, mg $CaCO_3$/ℓ	Hardness total, mg/ℓ	pH	Specific conductance, μmhos	Suspended solids, mg/ℓ	Total dissolved solids, mg/ℓ	Total solids, mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis. mg/ℓ	Fe undis. mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
C1	1.1	0	100	110	7.6	211	0	130	130	<0.5	37	1.1	<0.1	0.05	0.095	0.14	<2	10	<0.01	3.1	<0.1	130	<0.02
C2	1.0	0	100	110	7.0	211	0	110	110	<0.5	40	1.1	<0.1	0.05	0.10	0.15	<2	10	<0.01	3.2	<0.1	10	0.015
C3	1.5	0	120	1500	7.6	2200	13	2200	2210	<0.5	380	5.0	<0.1	0.06	0.58	0.64	4.0	140	0.36	19	<0.1	>800	0.042
C4	0.0	0	120	190	7.5	385	0	240	240	<0.5	64	1.6	<0.1	<0.05	0.10	0.10	<2	20	0.04	5.6	<0.1	91	<0.02
C5	0.0	0	73	>1000	6.4	2990	0	2900	2900	<0.5	340	4.2	<0.1	<0.05	0.005	<0.05	14	230	0.015	83	<0.1	>800	<0.02
C6	0.0	0	100	210	7.2	430	0	290	290	<0.5	65	1.5	<0.1	<0.05	0.21	0.21	<2	21	0.04	7.5	<0.1	92	<0.02
C7	3.5	188	350	1500	7.4	4200	0	3500	3500	<0.5	260	8.4	<0.1	<0.05	0.04	<0.05	18	140	<0.02	510	<0.1	>800	0.015
C8	0.5	0	120	250	7.6	490	0	300	300	<0.5	69	1.9	<0.1	0.05	0.16	0.16	<2	24	0.05	8.6	<0.1	96	<0.02
CP1																							

Table A-7. WATER ANALYSIS DATA FOR MARCH 1974.

Sample	Temp °C	Acidity, mg $CaCO_3$/ℓ	Alkalinity, mg $CaCO_3$/ℓ	Hardness total, mg/ℓ	pH	Specific conductance, μmhos	Suspended solids, mg/ℓ	Total dissolved solids, mg/ℓ	Total solids, mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis. mg/ℓ	Fe undis. mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
C1	0.5	<1	120	120	7.9	245	2.6	150	150	<0.5	51	1	<0.1	0.05	0.12	0.17	<2	11	<0.02	4.2	<0.1	6	0.043
C2	0.5	<1	120	120	7.9	240	0	110	110	<0.5	51	<1	<0.1	0.05	0.085	0.14	<2	11	<0.02	4.2	<0.1	7	<0.01
C3	0.5	<1	66	1500	7.4	2150	1.8	2000	2000	<0.5	450	3	<0.1	0.13	0.43	0.56	3.7	120	0.41	18	<0.1	>800	0.071
C4	0.5	<1	120	280	7.7	525	0	370	370	<0.5	97	1	<0.1	<0.05	0.17	0.17	<2	27	0.03	7.0	<0.1	250	0.017
C5	2.0	5.5	100	1300	7.3	2850	2.7	2760	2760	<0.5	420	3	<0.1	<0.05	0.021	<0.05	12	210	<0.02	74	<0.1	>800	0.012
C6	0.5	<1	100	340	6.9	700	4.2	480	480	<0.5	140	1	<0.1	<0.05	0.30	0.30	<2	34	0.04	11	<0.1	208	<0.01
C7	3.0	<1	330	2000	7.3	4250	3.4	3640	3640	<0.5	340	9	<0.1	<0.05	0.045	<0.05	17	150	<0.02	500	<0.1	>800	<0.01
C8	0.5	<1	110	360	7.7	630	5.0	460	460	<0.5	140	1	<0.1	0.07	0.17	0.24	<2	34	0.06	13	<0.1	270	<0.01
CP1	-	<1	240	2000	7.5	3000	67	2520	2590	<0.5	440	3	<0.1	0.16	4.4	4.6	4.5	210	0.55	19	<0.1	>800	17

Table A-8. WATER ANALYSIS DATA FOR APRIL 1974.

Sample	Temp °C	Acidity, mg $CaCO_3$/ℓ	Alkalinity, mg $CaCO_3$/ℓ	Hardness total, mg/ℓ	pH	Specific conductance, μmohs	Suspended solids, mg/ℓ	Total dissolved solids, mg/ℓ	Total solids, mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis. mg/ℓ	Fe undis. mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
C1	-	<1	110	120	8.2	190	10	130	130	<0.5	50	<1	<0.1	0.06	0.16	0.22	1.3	11	<0.01	3.7	<0.14	12	0.016
C2	-	<1	110	120	8.0	200	10	120	120	<0.5	54	<1	<0.1	0.06	0.91	0.97	1.2	12	<0.01	4.2	<0.14	12	0.01
C3	2.5	2	26	1400	7.3	1890	10	1950	1950	<0.5	460	3.0	<0.1	0.25	0.46	0.71	3.4	120	0.34	14	<0.14	160	0.11
C4	1.0	<1	143	470	8.1	853	9.8	690	700	<0.5	210	2.0	<0.1	<0.05	0.36	0.36	2.8	52	0.05	9.9	<0.14	200	0.015
C5	3.0	<1	173	1300	8.0	2600	43	2550	2590	<0.5	440	3.0	<0.1	<0.05	0.44	0.44	12	210	0.04	49	<0.14	700	0.022
C6	4.0	<1	120	460	7.8	785	10	590	660	<0.5	190	2.0	<0.1	<0.05	0.22	0.22	2.7	47	0.04	13	<0.14	170	0.012
C7	3.0	11	210	1850	7.7	2620	10	2520	2520	<0.5	460	4.0	<0.1	<0.05	0.82	0.82	4.7	190	0.26	-	<0.14	660	10
C8	4.5	<1	120	470	7.8	894	6.2	660	670	<0.5	210	1.9	<0.1	<0.05	-	-	3.0	49	0.04	17	<0.14	250	0.017
CP1	-	<1	300	1800	7.7	3970	45	3730	3780	<0.5	380	11	<0.1	<0.05	-	-	15	160	<0.01	44	<0.14	750	0.01

Table A-9. WATER ANALYSIS DATA FOR MAY 1974.

Sample	Temp °C	Acidity, mg $CaCO_3$/ℓ	Alkalinity, mg $CaCO_3$/ℓ	Hardness total, mg/ℓ	pH	Specific conductance, umhos	Suspended solids, mg/ℓ	Total dissolved solids, mg/ℓ	Total solids, mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis. mg/ℓ	Fe undis. mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
C1	4.0	<1	90	89	7.9	208	-	130	-	<0.5	50	1.7	<0.09	0.08	-	-	3.6	10	<0.01	3.6	<0.1	18	<0.01
C2	5.0	<1	96	96	7.9	209	-	110	-	<0.5	50	1	<0.09	0.08	-	-	3.6	10	<0.01	3.6	<0.1	18	<0.01
C3	12	<1	68	1700	7.6	2450	-	2120	-	<0.5	480	2.5	<0.09	<0.05	-	-	13	150	0.28	13	<0.1	160	0.058
C4	9.5	<1	120	330	8.1	528	-	340	-	<0.5	100	1.9	<0.09	0.05	-	-	5.6	27	<0.01	5.6	<0.1	130	<0.01
C5	14	<1	140	2000	7.9	3160	-	2760	-	<0.5	440	2.7	<0.09	<0.05	-	-	52	240	<0.01	52	<0.1	190	<0.01
C6	9	<1	120	250	8.1	541	-	400	-	<0.5	98	1.8	<0.09	0.05	-	-	9.8	25	<0.01	9.8	<0.1	130	<0.01
C7	8	<1	280	2400	7.6	5360	-	4690	-	<0.5	470	7.8	<0.09	<0.05	-	-	410	230	<0.01	410	<0.1	190	<0.01
C8	10	<1	130	300	8.2	650	-	480	-	<0.5	130	2.2	<0.09	0.07	-	-	18	31	<0.01	18	<0.1	150	<0.01
CP1	-	<1	220	1700	7.8	2680	-	2600	-	<0.5	450	3.8	<0.09	0.06	-	-	16	200	0.22	16	<0.1	170	5.5
RUN OFF	-	-	-	-	-	-	-	3100	-	<0.5	440	2.4	<0.09	<0.05	-	-	18	290	<0.01	18	<0.1	-	<0.01

Table A-10. WATER ANALYSIS DATA FOR JUNE 1974.

Sample	Temp °C	Acidity, mg $CaCO_3$/ℓ	Alkalinity, mg $CaCO_3$/ℓ	Hardness total, mg/ℓ	pH	Specific conductance, μmohs	Suspended solids, mg/ℓ	Total dissolved solids, mg/ℓ	Total solids, mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis. mg/ℓ	Fe undis. mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
C1	16	<1	64	80	7.7	147	-	110	-	<0.5	-	<1	<0.09	<0.08	-	-	<1	7.1	<0.01	2.6	<0.1	<1	0.018
C2	16	<1	66	95	7.8	147	-	110	-	<0.5	-	<1	<0.09	<0.08	-	-	<1	7.4	<0.01	2.8	<0.1	<1	<0.01
C3	20	<1	58	1600	7.7	2400	-	2100	-	<0.5	-	3.2	<0.09	<0.08	-	-	3.8	130	0.25	16	<0.1	830	0.624
C4	18	<1	88	150	7.5	263	-	180	-	<0.5	-	1.0	<0.09	<0.08	-	-	1.4	14	<0.01	4.0	<0.1	<1	<0.01
C5	19	<1	160	2000	7.8	3100	-	2800	-	<0.5	-	4.2	<0.09	<0.08	-	-	16	240	<0.013	92	<0.1	900	0.01
C6	18	<1	84	150	7.9	286	-	180	-	<0.5	-	1.0	<0.09	<0.08	-	-	1.4	16	<0.01	5.5	<0.1	4	<0.01
C7	-	<1	330	2200	7.5	5200	-	4400	-	<0.5	-	8.5	<0.09	<0.08	-	-	20	225	0.014	480	<0.1	650	<0.01
C8	18	<1	86	160	7.7	303	-	190	-	<0.5	-	1.0	<0.09	<0.08	-	-	1.4	16	0.31	5.7	<0.1	5	<0.01
CP1	-	<1	270	1600	7.2	2400	-	2100	-	<0.5	-	2.7	<0.09	<0.08	-	-	6.0	180	0.79	17	<0.1	200	5.7

APPENDIX B

WATER QUALITY DATA - IDARADO MINE SITE

Table B-1. DESCRIPTION OF WATER SAMPLE LOCATIONS AT IDARADO MINE SITE.

Sample designation	Description[a]
T1	Surface water sample above tailings and immediately below the confluence of Bridal Veil and Ingram Creeks.
T2	Mine drainage discharge.
T3	Surface water sample from Marshall Creek; contains some mine discharge.
T4	Surface water sample from San Miguel River immediately above active tailings pond No. 6.
T5	Surface water sample from Bear Creek at entry onto valley floor and upstream of tailings pond No. 6.
T6	Subsurface drainage sample from pipe extending beneath tailings pond No. 6.
T7	Groundwater seep sample below tailings pond No. 6.
T8	Surface water sample from San Miguel River below the confluence of Bear Creek.
T9	Surface water sample from San Miguel River at confluence of Prospect Creek.
T10	Surface water sample from San Miguel River at confluence of the South Fork of the San Miguel several kilometers below Telluride.
T11	Surface water sample from San Miguel River near Placerville, Colorado.
TP2,TP3,TP8	Groundwater samples from observation wells in vicinity of tailings pond No. 6.
TRP	Sample from tailings transport system at point of discharge.

[a] See figure 4 in text.

Table B-2. WATER ANALYSIS DATA FOR OCTOBER 1973.

Sample	Temp °C	Acidity, mg $CaCO_3$/ℓ	Alkalinity, mg $CaCO_3$/ℓ	Hardness total, mg/ℓ	pH	Specific conductance, μmho	Suspended solids, mg/ℓ	Total dissolved solids, mg/ℓ	Total solids, mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis. mg/ℓ	Fe undis. mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Ni mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
T1	1.6		31	110	6.6	170	5.3	<0.1	5.3	<0.1	42	<1	<0.1	<0.05	-	-	<1	3.2	<0.005	1.8	<0.05	37	0.57
T2	11.5		38	260	6.3	528	163	425	588	<0.1	110	<1	<0.1	<0.05	-	-	<1	5.2	2.6	11	0.05	200	2.1
T5	3.0		14	190	5.9	326	6.5	234	240	<0.1	66	<1	<0.1	<0.05	42	42	<1	3.8	3.4	3.9	0.06	63	3.6
T4	6.0		26	180	6.1	300	12	196	208	<0.1	63	<1	<0.1	<0.05	59	59	<1	3.3	1.3	4.0	<0.05	150	1.7
T5	5.0		70	96	7.9	163	0.85	80	81	<0.1	33	3.0	<0.1	<0.05	7.5	7.5	<1	2.2	<0.005	1.6	<0.05	86	0.018
T6	5.0		41	410	6.8	1130	58	542	600	<0.1	200	68	13	<0.05	-	-	36	1.2	1.2	75	<0.05	280	0.68
T7	5.6		50	220	6.5	391	92	292	384	0.1	80	1.0	<0.1	<0.05	-	-	<1	4.0	1.2	5.0	<0.05	160	1.4
T8	3.4		49	160	7.0	288	0.22	165	165	<0.1	60	5.0	<0.1	<0.05	5.5	5.5	<1	3.1	0.48	3.6	<0.05	200	0.47
T9	4.6		78	190	7.1	508	5.0	117	120	<0.1	68	1.0	<0.1	<0.05	16	16	1.0	4.0	0.22	5.1	<0.05	100	0.37
T10	4.6		85	200	7.0	504	1.5	142	144	0.1	69	9.9	<0.1	<0.05	18	18	1.0	4.3	0.14	5.5	<0.05	110	0.33
T11	-		99	190	7.2	339	1.1	173	174	<0.1	68	1.8	<0.1	<0.05	5.0	5.0	1.0	6.1	0.16	4.9	<0.05	92	0.18
T03																							
T08										0.19	100	5.0	<0.1	0.82			11	4.2	0.15	20	0.072	170	2.5

Table B-3. WATER ANALYSIS DATA FOR NOVEMBER 1975.

Sample	Temp °C	Acidity, mg CaCO3/ℓ	Alkalinity, mg CaCO3/ℓ	Hardness total, mg/ℓ	pH	Specific conductance, μmhos	Suspended solids, mg/ℓ	Total dissolved solids, mg/ℓ	Total solids, mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis. mg/ℓ	Fe undis. mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
T1	0.2	5	290	3.1	534	4.0	390	390	<0.1	100	<1	<0.1	<0.05	0.055	0.055	<1	2.6	0.10	5.5	<0.1	240	1.1
T2	11.1	17	360	6.1	899	170	580	750	<0.1	130	1.5	<0.1	<0.05	0.14	0.14	2.0	6.1	2.0	13	<0.1	<250	2.0
T3	4.0	2.5	150	5.8	270	6.6	200	210	<0.1	45	<1	<0.1	<0.05	0.13	0.13	<1	4.2	1.2	2.6	<0.1	100	2.1
T4	4.7	13	160	6.1	209	70	270	270	<0.1	60	1.0	<0.1	<0.05	0.062	0.062	<1	4.1	1.2	3.6	<0.1	140	1.5
T5	3.6	0	98	5.4	362	5.2	150	150	<0.1	54	<1	<0.1	<0.05	0.012	<0.05	1.0	4.8	<0.05	1.5	<0.1	45	<0.005
T6	5.8	0	>400	2.8	1860	1.2	940	940	0.15	180	56	9.7	<0.05	-	-	35	1.2		67	0.1	>400	0.015
T7	6.2	1.2	150	6.6	402	0.25	250	250	<0.1	64	1.0	<0.1	<0.05	0.0086	<0.05	1.2	4.4	0.75	4.4	<0.1	120	1.3
T8	7.9	36	150	5.6	482	2.9	200	200	<0.1	52	<1	<0.1	<0.05	0.025	<0.05	1.0	3.2	0.36	3.6	<0.1	120	0.63
T9	2.0	82	160	3.6	300	4.4	120	120	<0.1	54	<1	<0.1	<0.05	0.037	<0.05	1.7	4.6	0.13	5.9	<0.1	76	0.31
T10	2.3	45	250	6.6	420	1.6	300	300	<0.1	84	<1	<0.1	<0.05	0.068	0.068	<1	5.7	0.15	5.9	<0.1	180	0.20
T11	2.4	52	200	6.8	310	5.2	220	220	<0.1	60	6.4	<0.1	<0.05	0.090	0.090	<1	6.2	<0.05	4.2	<0.1	140	0.40
TP3																						
TP8		71	290	7.0	575		430		<0.1	93	3.0	<0.1	0.16			12	4.1	5.8	20	<0.1	250	6.0

Table B-4. WATER ANALYSIS DATA FOR DECEMBER 1973.

Sample	Temp °C	Acidity, mg $CaCO_3$/ℓ	Alkalinity, mg $CaCO_3$/ℓ	Hardness total, mg/ℓ	pH	Specific Conductance, μmhs	Suspended solids, mg/ℓ	Total dissolved solids, mg/ℓ	Total solids, mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis. mg/ℓ	Fe undis. mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
T1	0.1	17	44	570	6.3	870	-	840		<0.5	220	0.9	<0.01	<0.05	-	-	0.95	3.8	<0.01	12	0.20	180	20
T2	13	20	0.0	370	3.0	915	630	410	1040	<0.5	160	0.9	<0.01	<0.05	-	-	1.6	4.8	0.62	14	0.16	180	11
T3	0.7	19	2.0	310	4.3	557	35	450	490	<0.5	120	<1	<0.01	<0.05	0.04	<0.05	1.6	9.5	3.1	7.8	<0.16	220	39
T4	0.6	7	38	260	6.6	420	-	370	-	<0.5	98	<1	<0.01	<0.05	-	-	1.5	5.7	1.0	6.3	<0.16	92	14
T5	0.0	6	64	110	6.7	330	-	140	-	<0.5	51	<1	<0.01	<0.05	-	-	0.71	3.1	<0.01	1.7	<0.16	40	<0.01
T6	5.5	17	35	360	6.4	915	-	780	-	0.7	160	>100	17	<0.05	-	-	30	0.5	0.018	76	<0.16	160	0.038
T7	0.0	6	40	220	6.4	360	-	310	-	<0.5	78	<1	<0.01	<0.05	-	-	2.0	4.9	0.016	4.5	<0.16	78	12
T8	3.5	10	0.0	150	3.2	353	-	240	-	0.5	67	<1	<0.01	<0.05	-	-	2.2	3.1	<0.01	4.4	<0.16	41	0.37
T9	2.7	6	38	190	6.4	353	70	240	240	<0.5	68	17	<0.01	<0.05	0.026	<0.05	20	4.2	0.10	6.8	<0.16	84	0.19
T10	1.7	6	10	230	4.2	118	70	350	350	<0.5	48	0.8	<0.01	<0.05	0.069	0.069	0.58	5.5	0.098	2.8	<0.16	59	0.049
T11	0.6	6	59	210	6.1	212	-	200	-	<0.5	86	1.0	<0.01	<0.05	-	-	1.5	7.9	0.038	5.1	<0.16	130	0.071
TP3																							
TP3	-	6	35	270	7.3	545	340	340	680	<0.5	120	2.6	<0.01	<0.05	2.9	2.9	10.5	3.8	8.9	18	0.20	260	13

Table B-5. WATER ANALYSIS DATA FOR JANUARY 1974.

Sample	Temp °C	Acidity, mg $CaCO_3$/ℓ	Alkalinity, mg $CaCO_3$/ℓ	Hardness total, mg/ℓ	pH	Specific conductance, μmhos	Suspended solids, mg/ℓ	Total dissolved solids, mg/ℓ	Total solids, mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis. mg/ℓ	Fe un-dis. mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
T1	0.5	0.0	34	71	6.7	101	0	68	88	<0.5	32	1.0	<0.01	<0.05	0.0028	<0.05	4.0	1.5	<0.01	0.83	<0.14	17	0.062
T2	12	5.0	50	360	7.4	725	4.5	590	590	<0.5	160	<1	<0.01	<0.05	0.28	0.28	3.8	4.5	0.25	14	<0.14	190	11
T3	3.0	4.5	15	150	7.3	295	0	240	240	<0.5	68	<1	<0.01	<0.05	0.042	<0.05	-	4.5	1.5	4.0	<0.14	110	16
T4	2.5	3.0	15	130	6.8	325	0.17	260	260	<0.5	71	<1	<0.01	<0.05	0.022	<0.05	<2	4.2	0.87	4.4	<0.14	110	11
T5	0.0	1.9	73	120	7.4	188	0.03	150	150	<0.5	59	<1	<0.01	<0.05	0.0055	<0.05	<2	3.4	<0.01	1.9	<0.14	58	0.011
T6	4.5	0.0	42	440	9.0	1180	7.8	860	870	1.6	190	>100	16	<0.05	0.15	0.15	30	0.35	<0.01	66	<0.14	>400	0.008
T7	10	2.0	25	180	7.1	319	4.4	280	250	<0.5	75	<1	<0.01	<0.05	0.015	0.15	<2	3.8	0.015	4.2	<0.14	130	13
T8	30	3.0	10	110	5.9	250	152	220	370	<0.5	66	<1	<0.01	<0.05	-	-	<2	2.9	<0.01	3.9	<0.14	100	0.30
T9	4.0	0.0	76	160	7.1	310	0.095	230	230	<0.5	70	<1	<0.01	<0.05	-	-	<2	3.2	0.076	7.0	<0.14	120	0.17
T10	10	0.0	55	360	7.3	610	10	500	500	<0.5	160	<1	<0.01	<0.05	0.11	0.11	<2	7.5	0.099	3.6	<0.14	190	0.068
T11	10	0.0	60	230	7.2	395	0	330	330	<0.5	95	1.0	<0.01	<0.05	0.0055	<0.05	<2	7.7	0.018	4.6	<0.14	150	0.076
TP3																							
TP8																							

Table B-6. RATTR ANALYSIS DATA FOR FEBRUARY 1974.

Sample	Temp °C	Acidity, mg $CaCO_3$/ℓ	Alkalinity, mg $CaCO_3$/ℓ	Hardness (total), mg/ℓ	pH	Specific conductance, μmhs	Suspended solids, mg/ℓ	Total dissolved solids, mg/ℓ	Total solids, mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis. mg/ℓ	Fe undis. mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Hg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
T1																							
T2	9.0	9	56	400	7.6	780	16	630	650	0.5	170	<1	<0.1	<0.05	0.22	0.22	1.6	4.6	0.36	15	<0.1	320	9.4
T3	0.5	9	33	250	7.3	535	0	400	400	<0.5	93	<1	<0.1	<0.05	-	-	<1	8.1	1.6	8.1	<0.1	200	2.5
T4	0.0	4	42	190	8.5	390	2.3	290	290	<0.5	73	1.0	<0.1	<0.05	-	-	<1	4.3	0.32	5.2	<0.1	120	0.66
T5	0.0	5	81	120	7.7	230	2.6	110	110	<0.5	58	<1	<0.1	<0.05	-	-	<1	3.6	<0.02	1.9	<0.1	50	<0.02
T6	4.2	0	120	310	11.1	1170	21	780	800	2.1	170	>250	12	<0.05	0.46	0.46	33	0.15	<0.02	74	<0.1	320	<0.039
T7																							
T8	2.0	4	57	110	7.6	309		190		<0.5	67	<1	<0.1	<0.05	-	-	2.2	2.8	<0.02	5.2	<0.1	93	0.39
T9	0.5	1	86	170	7.6	359	1.8	240	240	<0.5	69	1.5	<0.1	<0.05	0.060	0.060	1.3	4.3	0.03	7.0	<0.1	90	0.16
T10	0.5	0	55	180	7.4	363	2.2	250	250	<0.5	73	<1	<0.1	<0.05	0.16	0.16	<1	4.3	0.04	2.3	<0.1	110	0.038
T11	0.5	0	49	230	7.2	490	70	310	310	<0.5	79	1.6	<0.1	<0.05	-	-	<1	9.2	<0.02	5.2	<0.1	40	0.018
TP3																							
TP8																							

Table B-7. WATER ANALYSIS DATA FOR MARCH 1974

Sample	Temp °C	Acidity, mg $CaCO_3$/ℓ	Alkalinity, mg $CaCO_3$/ℓ	Hardness total, mg/ℓ	pH	Specific conductance, μmhos	Suspended solids, mg/ℓ	Total dissolved solids, mg/ℓ	Total solids, mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis. mg/ℓ	Fe undis. mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
T1																							
T2	14	1.0	51	450	7.3	760	160	600	760	<0.5	300	1	<0.1	<0.05	1.3	1.3	<2	4.8	0.25	15	<0.1	320	0.71
T3	3.0	3.0	10	160	6.5	335	0.26	220	220	<0.5	94	<1	<0.1	<0.05	0.034	<0.05	<2	5.1	0.93	4.8	<0.1	140	0.12
T4	1.5	4.0	18	190	6.9	390	0.56	270	270	<0.5	99	<1	<0.1	<0.05	0.015	<0.05	<2	4.8	0.35	5.2	<0.1	150	0.08
T5	2.0	<1	77	120	7.0	315	0.64	120	120	<0.5	78	<1	<0.1	<0.05	0.0039	<0.05	<2	3.7	<0.02	2.2	<0.1	50	<0.01
T6	4.0	<1	51	430	9.6	1170	2.5	790	790	0.4	320	320	11	<0.05	0.045	<0.05	29	0.31	<0.02	70	<0.1	<400	0.011
T7																							
T8	4.0	<1	60	140	7.5	270	0.69	170	170	<0.5	90	<1	<0.1	<0.05	0.0071	<0.05	<2	2.9	<0.02	3.9	<0.1	74	0.33
T9	1.0	<1	75	170	7.7	343	1.9	230	230	<0.5	95	<1	<0.1	<0.05	0.14	0.14	<2	4.8	0.10	7.3	<0.1	91	0.20
T10	1.0	<1	64	360	7.4	700	2.0	490	490	<0.5	260	<1	<0.1	<0.05	0.12	0.12	<2	8.3	0.11	3.9	<0.1	270	0.069
T11	2.0	<1	98	250	8.0	475	1.9	320	320	<0.5	150	1	<0.1	<0.05	0.099	0.099	<2	10	<0.02	5.6	<0.1	140	0.065
TP3	-	3	69	890	7.1	2000	-	1650	-	<0.5	440	8	<0.1	<0.08	-	-	28	8.1	25	45	<0.1	<800	21
TP8																							

Table 8-8. WATER ANALYSIS DATA FOR APRIL 1974.

Sample	Temp °C	Acidity, mg $CaCO_3$/ℓ	Alkalinity, mg $CaCO_3$/ℓ	Hardness total, mg/ℓ	pH	Specific conductance, μmohs	Suspended solids, mg/ℓ	Total dissolved solids, mg/ℓ	Total solids, mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis. mg/ℓ	Fe undis. mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
T1																							
T2	15	50	45	350	7.4	749	36	610	-	<0.5	260	<1	<0.1	<0.05	0.81	0.81	1.6	4.6	0.32	19	0.14	240	0.63
T3	2.5	1	30	250	7.5	420	11	390	-	<0.5	130	<1	<0.1	<0.05	0.017	<0.05	1.6	6.5	1.5	6.3	<0.14	180	0.25
T4	3.0	2	36	250	7.7	468		370	-	<0.5	150	3.8	<0.1	<0.05	-	-	<1	5.9	0.72	6.9	<0.14	150	0.14
T5	3.0	<1	79	130	7.8	192		140	-	<0.5	76	<1	<0.1	<0.05	-	-	<1	4.0	<0.01	2.3	<0.14	32	0.041
T6	6.0	2	56	460	7.7	1100	6.4	930	-	<0.5	320	52	4.3	<0.05	0.52	0.52	32	1.2	3.3	62	<0.14	170	0.42
T7	3.0	2	45	260	7.7	437	70	340	-	<0.5	150	<1	<0.1	<0.05	0.015	<0.05	1.7	5.8	0.11	6.0	<0.14	150	1.8
T8	3.5	<1	55	200	7.7	353	70	250	-	<0.5	100	<1	<0.1	<0.05	0.012	<0.05	1.4	4.5	0.020	5.0	<0.14	97	0.30
T9	4.5	<1	85	190	7.8	395	70	230	-	<0.5	100	<1	<0.1	<0.05	0.62	0.62	1.9	5.0	0.12	7.5	<0.14	85	0.22
T10	6.0	1	56	170	7.8	353	0.05	280	-	<0.5	91	<1	<0.1	0.13	0.14	0.27	<1	4.0	0.11	2.5	<0.14	72	0.042
T11	2.0	<1	95	200	8.0	406	8.2	240	-	<0.5	98	1	<0.1	<0.05	0.20	0.25	<1	7.4	0.046	4.8	<0.14	91	0.056
TP3	-	38	64	700	7.2	680	15	-	-	<0.5	330	4.4	<0.1	<0.05	1.0	1.0	25	7.1	55	39	<0.14	-	17
TP8	-	51	<1	250	4.2	1620	42	-	-	<0.5	170	7.4	0.16	<0.05	1.1	1.1	12	3.1	2.4	24	<0.14	260	19

Table B-9. WATER ANALYSIS DATA FOR MAY 1974.

Sample	Temp °C	Acidity, mg $CaCO_3$/ℓ	Alkalinity, mg $CaCO_3$/ℓ	Hardness (total), mg/ℓ	pH	Specific conductance, μmho	Suspended solids, mg/ℓ	Total dissolved solids, mg/ℓ	Total solids, mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis. mg/ℓ	Fe undis. mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
T1	0.0	<1	14	40	7.1	53	-	80	-	<0.5	20	<1	<0.09	0.05	-	-	<1	0.75	0.01	0.59	<0.10	70	0.034
T2	15	<1	40	360	7.9	811	-	520	-	<0.5	270	<1	<0.09	0.05	-	-	1.4	4.1	0.29	17	0.14	220	0.60
T3	1.5	2	6.4	170	6.7	270	-	180	-	<0.5	74	<1	<0.09	0.05	-	-	<1	3.7	1.4	1.6	<0.10	60	3.7
T4	1.5	1	24	89	7.0	233	-	160	-	<0.5	70	<1	<0.09	0.05	-	-	<1	2.6	0.54	2.1	<0.10	60	1.1
T5	2.0	<1	85	99	7.9	211	-	120	-	<0.5	72	<1	<0.09	<0.05	-	-	<1	5.0	<0.01	1.8	<0.10	18	0.01
T6	5.0	1	56	62	7.7	1170	-	1080	-	<0.5	360	28	3.0	0.05	-	-	40	1.0	4.9	66	<0.10	190	0.41
T7	5.0	1	30	110	7.6	256	-	190	-	<0.5	80	<1	<0.09	0.06	-	-	<1	3.0	0.50	2.6	<0.10	59	1.2
T8	2.0	<1	38	110	7.6	250	-	190	-	<0.5	81	<1	<0.09	0.06	-	-	<1	3.0	0.29	2.7	<0.10	52	0.90
T9	4.5	<1	66	120	7.8	256	-	200	-	<0.5	85	<1	<0.09	0.05	-	-	<1	5.7	0.16	4.2	<0.10	50	0.35
T10	5.8	<1	64	190	7.8	411	-	300	-	<0.5	110	<1	<0.03	<0.05	-	-	<1	5.7	0.13	2.7	<0.10	100	0.028
T11	4.0	<1	94	140	8.1	315	-	190	-	<0.5	91	<1	<0.01	0.05	-	-	1.0	6.6	0.05	5.6	<0.10	50	0.050
TP5	-	-	-	-	7.3	2030	-	-	-	<0.5	310	5.5	<0.09	0.05	-	-	27	8	41	40	<0.10	110	29
TP8	-	4	47	270	7.5	754	-	490	-	<0.5	200	3.0	0.11	0.06	-	-	12	3.4	2.8	22	<0.10	180	9.2
TP2	-	14	150	820	7.3	2680	-	2270	-	<0.5	600	2.5	<0.09	<0.05	-	-	33	17	37	38	<0.10	180	54
TRP	-	<1	160	3101		1200	-	720	-	1.9	260	>250	20	<0.05	-	-	27	0.04	<0.01	53	0.21	180	<0.01

Table B-10. WATER ANALYSIS DATA FOR JUNE 1974.

Sample	Temp °C	Acidity, mg $CaCO_3$/ℓ	Alkalinity, mg $CaCO_3$/ℓ	Hardness total, mg/ℓ	pH	Specific conductance, μmhos	Suspended solids, mg/ℓ	Total dissolved solids, mg/ℓ	Total solids, mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis. mg/ℓ	Fe undis. mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
T1	2.0	<1	17	32	7.2	42	-	45	-	<0.5	-	<1	<0.09	<0.08	-	-	<1	0.73	0.055	0.51	<0.1	<1	0.16
T2	13	<1	42	340	7.1	670	-	530	-	<0.5	-	<1	<0.09	<0.08	-	-	1.5	7.4	2.4	10	<0.1	140	2.5
T3	4.5	2	21	130	6.6	270	-	180	-	<0.5	-	<1	<0.09	<0.08	-	-	<1	3.0	0.96	2.8	<0.1	70	2.1
T4	3.5	1	18	78	6.5	172	-	100	-	<0.5	-	<1	<0.09	<0.08	-	-	<1	1.7	0.36	1.8	<0.1	11	0.84
T5	3.0	<1	38	52	7.0	90	-	44	-	<0.5	-	<1	<0.09	<0.08	-	-	<1	1.4	<0.01	0.9	<0.1	<1	<0.01
T6	6.0	<1	60	560	7.6	1440	-	1100	-	<0.5	-	28	2.0	<0.08	-	-	41	1.1		68	<0.1	540	0.42
T7	3.5	1.5	24	88	7.2	192	-	42	-	<0.5	-	<1	<0.09	<0.08	-	-	<1	1.9	0.30	1.9	<0.1	23	0.92
T8	3.0	1	21	80	6.8	172	-	110	-	<0.5	-	<1	<0.09	<0.08	-	-	<1	1.8	0.23	1.8	<0.1	16	0.62
T9	5.0	<1	47	94	7.4	190	-	130	-	<0.5	-	<1	<0.09	<0.08	-	-	<1	2.4	0.14	2.8	<0.1	14	0.41
T10	4.0	<1	58	200	7.0	370	-	250	-	<0.5	-	<1	<0.09	<0.08	-	-	<1	4.4	0.11	2.2	<0.1	80	0.042
T11	5.5	<1	53	120	7.6	230	-	130	-	<0.5	-	<1	<0.09	<0.08	-	-	<1	4.1	0.043	2.6	<0.1	14	0.0845
TP3	-	36	170	1400	7.3	2500	-	2400	-	<0.5	-	1.9	<0.09	<0.08	-	-	36	17	71	37	<0.1	>1200	72
TP8	-	<1	36	290	6.8	680	-	400	-	<0.5	-	1.1	<0.09	<0.08	-	-	11	3.9	3.4	18	<0.1	290	6.0

APPENDIX C

EDNA MINE SITE - SATURATED SOIL PASTE AND PLANT NUTRIENT ANALYSES

Table C-1. SATURATED PASTE ANALYSES OF SPOIL SAMPLES - EDNA MINE.

Sample no.	pH	Cond.[a]	Ca ppm	Mg ppm	Na ppm	K ppm	CO_3 ppm	HCO_3 ppm	Cl ppm	SO_4 ppm	NO_3 ppm
NSI 0-2	8.2	2979	45	122	32	32	0.0	193	20	590	53
2-4	8.0	3191	50	226	41	33	0.0	162	15	670	87
NSII 0-4	8.1	4475	42	320	209	44	0.0	199	15	1000	115
NSIII 0-2	8.2	3967	52	270	41	24	0.0	280	15	820	77
2-4	8.1	3402	41	247	57	35	0.0	149	15	800	99
MSI 0-2	8.0	3699	42	342	27	31	0.0	181	15	850	81
2-4	8.1	3826	46	290	28	31	0.0	149	15	830	74
MSII 0-2	8.2	1186	11	82	9	21	0.0	187	15	151	9
2-4	8.1	1539	15	107	18	23	0.0	174	15	180	65
MSIII 0-2	7.9	3247	47	207	16	31	0.0	162	15	710	12
2-4	8.1	3360	39	247	23	29	0.0	212	15	690	6
SSI 0-4	8.1	3826	42	335	31	27	0.0	168	15	820	130
SSII 0-2	7.8	1765	20	116	14	12	0.0	168	15	320	37
2-4	7.8	3064	49	182	27	19	0.0	143	15	640	99

[a] micro-mohs/cm.

Table C-2. SATURATED PASTE ANALYSES OF DRILL CUTTINGS AND NATIVE SOIL - EDNA MINE.

Sample no.	pH	Cond.[a]	Ca ppm	Mg ppm	Na ppm	K ppm	CO_3 ppm	HCO_3 ppm	Cl ppm	SO_4 ppm	NO_3 ppm
DC- 0-10	8.1	2753	34	140	83	22	0.0	168	15	420	223
DC-10-20	8.1	2372	31	130	77	16	0.0	93	8	390	136
DC-20-30	8.0	3600	50	107	71	46	0.0	162	15	700	74
DC-30-40	8.0	3374	44	227	103	51	0.0	311	75	740	43
DC-40-50	8.3	2753	28	205	79	58	0.0	206	15	470	99
soil	8.1	339	3	9	13	11	0.0	124	20	30	53

[a]micro-mohs/cm.

Table C3. PLANT NUTRIENT ANALYSES OF SPOIL SAMPLES - EDNA MINE.

Sample no.	pH	% O.M.	Lime	P ppm	K ppm	NO_3-N ppm	Zn ppm	Fe ppm	Texture
NSI									
0-2	7.5	3.8	Med	2	124	4	15.80	30.0	Sandy clay
2-4	7.4	4.6	Med	2	121	6	19.60	45.0	Sandy clay
NSII									
0-4	7.2	3.1	Med	3	140	9	17.80	71.0	Sandy clay
NSIII									
0-2	6.6	4.8	Med	7	104	5	8.30	117.0	Sandy clay
2-4	7.4	4.0	Med	2	128	7	7.50	46.0	Sandy clay
MSI									
0-2	7.3	3.9	Med	7	128	8	18.00	69.0	Clay
2-4	7.5	3.1	Med	4	143	5	16.48	76.0	Clay
MSII									
0-2	7.8	3.6	Med	0	136	1	12.96	37.6	ISS[a]
2-4	7.7	3.9	Med	0	149	6	21.60	45.0	Clay
MSIII									
0-2	7.5	3.0	Med	2	146	2	8.30	39.0	Sandy clay
2-4	7.1	3.4	Med	4	120	0	9.30	27.8	Sandy clay
SSI									
0-4	7.5	6.1	Med	1	93	9	16.60	27.6	Sandy clay
SSII									
0-2	7.5	5.9	Med	2	85	3	7.20	35.0	Sandy clay
2-4	7.1	3.5	Med	4	93	8	8.38	57.0	Sandy clay

[a] Insufficient sample.

Table C-4. PLANT NUTRIENT ANALYSES OF DRILL CUTTINGS AND NATIVE SOIL - EDNA MINE.

Sample no.	pH	% O.M.	Lime	P ppm	K ppm	NO_3-N ppm	Zn ppm	Fe ppm	Texture
DC- 0-10	7.7	3.0	Med	0	108	16	39.00	30.4	Sandy clay
DC-10-20	7.8	1.7	Med	0	70	8	7.40	20.4	Sandy clay loam
DC-20-30	7.5	3.6	Med	0	133	7	29.00	29.9	Sandy clay
DC-30-40	7.5	3.2	Med	0	144	8	80.00	37.6	Sandy clay
DC-40-50	7.6	5.0	Med	0	151	7	31.60	45.0	Sandy clay
soil	6.6	4.3	Med	6	301	3	1.70	44.4	Sandy clay loam

APPENDIX D

NAVAJO MINE SITE - SATURATED SOIL PASTE AND PLANT NUTRIENT ANALYSES

Table D-1. SATURATED SOIL PASTE ANALYSES OF SPOIL AND OVERBURDEN - NAVAJO MINE.

Sample no.[b]	pH	Cond.[a]	Ca ppm	Mg ppm	Na ppm	K ppm	CO_3 ppm	HCO_3 ppm	Cl ppm	SO_4 ppm	NO_3 ppm
R-1	8.1	3600	34	140	500	25	0.0	174	15	740	189
R-2	8.1	2217	22	190	218	16	0.0	130	10	270	170
R-3	8.0	4744	34	275	890	29	0.0	168	50	930	121
R-4	7.9	5224	41	307	857	33	0.0	162	40	1230	170
R-5	4.6	11873	35	831	2150	24	0.0	19	55	2340	713
R-6	7.8	4024	24	147	644	30	0.0	112	35	670	409
FB1	8.2	9092	36	220	1840	21	0.0	634	55	1500	360
FB2	8.1	11916	41	297	2277	53	0.0	734	20	1750	1829
FB3	7.9	7158	44	170	1271	34	0.0	454	20	1220	744

[a] micro-mohs/cm.

[b] Samples R-1 through R-6 are surface spoil samples. Samples FB1, FB2, and FB3 are composited samples of fresh overburden.

Table D-2. PLANT NUTRIENT ANALYSES OF SPOIL AND OVERBURDEN - NAVAJO MINE.

Sample no.	pH	% O.M.	Lime	P ppm	K ppm	NO_3-N ppm	Zn ppm	Fe ppm	Texture
R-1	7.3	1.3	Med	2	101	12	0.59	9.9	Sandy clay loam
R-2	7.9	0.2	Med	3	73	9	0.16	4.4	Sandy loam
R-3	7.5	2.0	Med	5	206	11	1.58	16.4	Sandy clay loam
R-4	7.3	2.6	Low	5	190	20	1.05	19.7	Sandy clay loam
R-5	4.3	6.5	Low	7	153	98	17.80	272.0	Sandy clay loam
R-6	7.4	0.6	Low	1	289	48	0.49	7.1	Clay
FB1	7.1	1.1	Low	4	148	30	2.04	134.0	Clay
FB2	6.9	4.5	Low	9	181	160	6.26	124.0	Clay
FB3	7.0	3.9	Med	6	194	90	3.40	74.0	Sandy clay loam

APPENDIX E

IDARADO MINE SITE - SATURATED SOIL PASTE AND PLANT NUTRIENT ANALYSES

Table E-1. SATURATED PASTE ANALYSES OF TAILINGS - IDARADO MINE.

Sample no.	pH	Cond.[a]	Ca ppm	Mg ppm	Na ppm	K ppm	CO_3 ppm	HCO_3 ppm	Cl ppm	SO_4 ppm	NO_3 ppm
4-2	7.6	2612	52	55	61	37	0.0	87	15	480	112
5-2	7.5	2372	54	18	49	29	0.0	81	15	480	96
5-3	7.6	2485	51	55	58	48	0.0	87	15	450	105
5-5	7.6	3078	62	122	39	24	0.0	93	15	440	558
5-6	7.6	2428	52	76	29	33	0.0	99	15	550	50
6-2	8.0	537	6	16	6	12	0.0	118	10	61	6
6-5	7.7	2047	39	15	64	58	0.0	105	20	240	3
2-1	7.8	2499	54	34	12	23	0.0	105	10	450	53
2-2	7.9	2442	46	39	64	29	0.0	171	25	370	130
3-2	7.6	2824	52	92	54	59	0.0	93	35	590	43

[a]micro-mohs/cm.

Table E-2. PLANT NUTRIENT ANALYSES OF TAILINGS - IDARADO MINE.

Sample no.	pH	% O.M.	Lime	P ppm	K ppm	NO_3-N ppm	Zn ppm	Fe ppm	Texture
4-2	7.4	0.7	Med	0	36	2	122.0	25.3	ISS[a]
5-2	7.4	0.3	Med	1	25	7	114.0	14.4	Sand
5-3	7.5	0.4	Med	0	39	6	34.8	+9.99	Sand
5-5	7.4	0.3	Med	3	25	36	167.0	22.5	Loamy sand
5-6	7.3	0.4	Med	0	24	3	148.0	12.9	Loamy sand
6-2	7.8	0.2	Med	1	21	0	150.0	16.9	Loamy sand
6-5	7.5	1.4	Med	0	36	0	41.0	23.2	Loamy sand
2-1	7.6	0.3	Med	2	29	3	230.0	12.0	Loamy sand
2-2	7.7	0.2	Med	6	58	12	310.0	41.8	Sandy loam
3-2	7.5	1.2	Med	1	70	10	211.0	64.4	Silty loam

[a]Insufficient sample.

APPENDIX F

COLUMN LEACHING DATA

Table F-1. DESCRIPTIONS OF EDNA MINE SAMPLES USED IN LEACHING TESTS.

Sample	Description
NSI	Sample formed by compositing samples every 15 cm to a depth of 120 cm near the up-slope limit of mining on the north and of the Edna spoils. Gray and black shale fragments with some sandstone. Shales appear to crumble and decompose readily in water. Bulk volume of sample is 1293 cm^3 and dry weight is 1829 gm. Length of column is 35 cm. Conductivity of saturated paste = 3000 µmohs/cm.
MSII	Sample formed by compositing samples every 15 cm between the depths of 60 and 120 cm near the center of mined area. Gray and black shale fragments. Relatively more stable in water than other samples. Bulk volume of sample is 1293 cm^3 and dry weight is 1941 gm. Length of column is 35 cm. Conductivity of saturated paste = 1540 µmohs/cm.
SSI	Sample formed by compositing samples every 15 cm to a depth of 120 cm at the south end of mined area disturbed before 1962. Gray and black shale fragments which crumble readily in water. Bulk volume of sample is 1367 cm^3 and dry weight is 1922 gm. Length of column is 37 cm. Conductivity of saturated paste = 3830 µmohs/cm.
DC-10-20	Sample formed by compositing samples between 3 and 6 meters below the surface from four locations along the highwall. Fraction larger than 0.351 mm used in column. Mostly light tan shale and siltstone with some gray and black shale. Bulk volume is 1960 cm^3 and dry weight is 1320 gm. Length of column is 26 cm. Conductivity of saturated paste = 2370 µmohs/cm.

Table F-1. DESCRIPTIONS OF EDNA MINE SAMPLES USED IN LEACHING TESTS. (continued)

Sample	Description
DC-30-40	Sample formed by compositing samples between 10 and 13 meters below the surface from four locations along the highwall. Fraction larger than 0.351 mm used in column. Gray and black shale cuttings. Bulk volume is 1071 cm^3 and dry weight is 1496 gm. Length of column is 29 cm. Conductivity of saturated paste = 3370 µmohs/cm.
DC-40-50	Sample formed by compositing samples between 13 and 16 meters below the surface from four locations along the highwall. Fraction larger than 0.351 mm used in column. Gray and black shale cuttings. Bulk volume is 997 cm^3 and dry weight is 1439 gm. Length of column is 27 cm. Conductivity of saturated paste = 2750 µmohs/cm.

Table F-2. LEACHING DATA FOR COLUMNS OF SPOILS AND DRILL CUTTINGS - EDNA MINE.

Sample	Volume of leachate cm^3	pH	Specific conduct. µmohs/cm
NSI	279	7.5	3250
	642	7.8	2330
	81?	8.1	816
	2761	8.0	510
	3174	7.9	333
	3487	8.0	260
	3821	8.0	280
	4275	7.9	240
	5300	8.0	237
	5690	8.0	222
	6057	8.0	204
MSII	931	7.1	814
	1152	7.8	300
	1823	8.0	350
	3367	7.8	187
	5127	8.2	130
	8718	8.3	120
	9302	8.2	110
SSI	271	7.4	3850
	513	7.4	3820
	2259	7.6	2030
	4006	7.8	500
	6966	7.7	500
	12984	8.0	150
	14270	7.9	120

Sample	Volume of leachate cm^3	pH	Specific conduct. µmohs/cm
DC-10-20	101	7.7	980
	656	7.9	1140
	3368	7.8	230
	3426	8.0	230
	6331	8.0	126
	7899	8.0	91
	8918	7.9	78
	10368	7.9	76
	10638	-	74
DC-30-40	133	7.2	2860
	2822	7.7	930
	3601	7.8	210
	5407	7.8	240
	6109	7.9	161
	6258	8.0	202
	6319	8.0	240
	6499	8.0	222
DC-40-50	639	7.9	1900
	1009	8.0	910
	1353	8.0	560
	1688	7.9	370
	2016	7.9	303
	2520	8.0	260
	3383	7.9	190
	5079	8.0	150
	6697	8.1	140
	7121	8.1	170
	7313	8.1	225
	7402	8.1	250
	7460	8.2	278

Table F-3. DESCRIPTION OF NAVAJO MINE SAMPLES USED IN LEACHING TESTS.

Sample	Description
FB1	Sample formed by compositing samples between 2 and 5 meters below surface and above No. 8 seam in Barber pit. Fraction larger than 0.351 mm used in column. Tan shale and siltstone with some yellow clay nodules and some gray shale. Crumbles readily in water. Bulk volume of sample is 1182 cm^3 and dry weight is 1467 gm. Column length 32 cm. Conductivity of saturated paste = 9100 µmohs/cm.
FB2	Sample formed by compositing samples between the No. 8 and No. 7 seams in the Barber pit. Fraction larger than 0.351 mm used in column. Light gray shale with some tan shale and clay. Bulk volume of sample is 1182 cm^3 and dry weight is 1727 gm. Column length is 32 cm. Conductivity of saturated paste = 11900 µmohs/cm.
FB3	Sample formed by compositing samples between the No. 7 and No. 6 seams in the Barber pit. Fraction larger than 0.351 mm used in column. Light gray shale with some tan shale and clay. Bulk volumn of sample is 1000 cm^3 and dry weight is 1265 gm. Length of column is 27 cm. Conductivity of saturated paste = 7200 µmohs/cm.

Table F-4. LEACHING DATA FOR COLUMNS OF OVERBURDEN - NAVAJO MINE.

Sample	Volume of leachate cm^3	pH	Specific conduct. µmohs/cm
FB1	457	7.2	8200
	729	7.4	8700
	1007	7.3	8000
	1891	7.2	6900
	2511	7.2	4100
	3220	7.2	3400
	3602	7.2	3100
	5644	7.1	2630
	7226	7.2	2150
	7913	7.6	2340
	8254	7.5	2380
	8492	7.5	2220
	9903	7.4	1300
	10345	7.6	1250
	12005	7.7	1040
	14508	8.0	493
FB2	175	6.7	7100
	2776	6.9	3640
	4794	7.2	1760
	5501	7.4	1960
	7756	7.4	966
FB2	8187	7.4	1140
	8543	7.5	1080
	8880	7.6	1000
	9073	7.6	950
	11049	-	470
	12528	8.0	470
FB3	1966	6.9	4650
	4261	6.9	1920
	4488	7.0	2170
	5017	7.0	1970
	5334	7.2	1840
	5631	7.3	1670
	6073	7.3	1450
	7946	-	625
	9050	-	377
	9831	8.0	384

APPENDIX G

INFILTRATION DATA

Table G-1. INFILTRATION DATA AT EDNA MINE SITE.

Time min.	Cumulative infiltration, cm			
	Graded spoils #1	Graded spoils #2	Native soil #1	Native soil #2
0.0	0.0	0.0	0.0	0.0
0.5	1.2	0.4	1.0	0.8
1.0	1.7	0.8	1.6	1.5
1.5	1.8	-	1.9	1.7
2.0	1.8	1.0	2.2	2.0
3.0	1.83	1.4	2.8	2.4
4.0	1.9	1.7	3.4	3.0
6.0	-	2.2	4.3	3.8
8.0	2.1	-	-	-
10.0	2.3	2.7	5.9	5.1
15.0	2.3	3.3	8.1	6.4
20.0	-	-	10.0	-
30.0	2.5	4.4	-	9.8
45.0	-	-	-	12.8
60.0	3.1	6.2	-	15.6
90.0	3.5	7.9	-	-
120.0	3.8	9.3	-	-
150.0	-	10.5	-	-

Table G-2. INFILTRATION DATA AT NAVAJO MINE SITE.

Time min.	Cumulative infiltration, cm			
	Sprinkler plot - 1	Sprinkler plot - 2	Drip Irrig. plot - 1	Native soil
0.0	0.0	0.0	0.0	0.0
0.5	0.5	0.5	0.4	1.3
1.0	0.8	0.8	0.45	1.8
2.0	0.9	0.9	0.51	2.4
4.0	-	-	0.51	3.3
5.0	1.1	1.2	-	-
6.0	-	-	0.56	3.9
8.0	-	-	-	4.3
10.0	1.4	1.65	0.64	4.6
15.0	-	-	-	5.5
20.0	1.65	2.0	-	6.2
25.0	-	-	-	7.0
30.0	-	-	1.0	7.8
35.0	-	-	-	8.6
40.0	2.3	2.7	-	9.3
45.0	-	-	-	10.0
60.0	-	3.0	-	-
70.0	3.0	-	-	-
90.0	-	3.6	1.5	-
100.0	3.7	-	-	-
130.0	4.2	-	1.65	-
160.0	5.2	-	2.4	-

Table G-3. INFILTRATION DATA AT IDARADO SITE.

Time min.	Cumulative infiltration, cm	
	Tailings pond #5	Tailings pond #6
0.0	0.0	0.0
0.5	1.1	0.8
1.0	1.7	1.2
1.25	1.8	-
1.5	-	1.4
2.0	2.3	1.4
4.0	3.1	1.6
6.0	3.6	1.8
10.0	4.0	2.0
15.0	4.3	2.3
30.0	4.9	3.0
60.0	5.9	3.6
90.0	7.0	4.1
120.0	8.1	4.5
150.0	9.5	-